IV. *On the Influence of Temperature on the Electric Conducting-Power of Alloys.* By

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THE influence of temperature on the electric conducting-power of the pure metals in a solid state has been proved to be very great*, and as very little is as yet known with regard to the influence of temperature on the electric conducting-power of alloys, we undertook this research in order, if possible, to discover the law which regulates this property.

For the sake of clearness, we have thought it advisable to divide this subject into four parts, and they will be treated of in the following order:—

1. Experiments on the influence of temperature on the electric conducting-power of alloys composed of two metals.
2. Experiments on the influence of temperature on the electric conducting-power of some alloys composed of three metals.
3. On a method by which the conducting-power of a pure metal may be deduced from that of the impure one.
4. Miscellaneous and general remarks.

I. *Experiments on the Influence of Temperature on the Electric Conducting-power of Alloys composed of two Metals.*

It will be as well to mention that, from the few experiments already published on the influence of temperature on the conducting-power of alloys, we had at the commencement of the research some idea of the law which regulates this property, and having found after a few experiments our supposition confirmed, we were able to shape the course we intended to pursue, in such a manner as to curtail the number of alloys to be experimented with. Thus, with the alloys made of the metals lead, tin, cadmium, and zinc with one another, instead of using the alloys

$$Pb_6Sn,\ Pb_4Sn,\ Pb_2Sn,\ PbSn,\ PbSn_2,\ PbSn_4,\ PbSn_6,$$

and testing in the same manner the tin-cadmium, tin-zinc, cadmium-zinc alloys, we only used the following,

$$Sn_6Pb,\ Sn_4Cd,\ Sn_2Zn,\ PbSn,\ ZnCd_2,\ SnCd_4,\ CdPb_6,$$

thus forming a mixed but complete series. Other groups of alloys have been treated in

* Philosophical Transactions, 1862, p. 1.

a similar manner. The reason for grouping alloys made of different metals under different heads has already been elsewhere discussed*. It has also been only considered necessary to experiment on one wire of each alloy, as the results obtained agree, in most cases, very closely with those calculated, and as it has been proved by a few determinations, which are given in Table I., that the same values were obtained for the percentage decrement in the conducting-power of the alloy between 0° and 100°, when series of determinations were made with two wires of the same alloy.

TABLE I.

Alloy.	Volumes per cent.	Percentage decrement observed between 0° and 100°.	Remarks.
Gold-copper (hard drawn) ...	98·63 of Au	21·87	Series made with wires of different specimens of the alloy.
Gold-copper (hard drawn) ...	98·38 „	21·75	
Gold-silver † (hard drawn)...	52·08 „	6·50	
Gold-silver (hard drawn) ...	52·08 „	6·48	
Gold-silver (annealed).........	52·08 „	6·72	
Gold-silver (annealed).........	52·08 „	6·70	Two series of determinations made with the same wire.
Gold-silver (annealed).........	52·08 „	6·71	
Gold-silver (annealed).........	79·86 „	10·15	
Gold-silver (annealed).........	79·86 „	10·21	
Tin-cadmium	23·50 of Sn	28·89	Series made with different wires of the same specimen of the alloy.
Tin-cadmium	23·50 „	29·08	

The method and apparatus employed for the determination of the conducting-power at different temperatures was the same as that described and used for the experiments on the pure metals†. We have, however, in many cases only taken observations at three intervals, as we found that almost the same formula was deduced from observations made at three different temperatures as from seven, especially when the temperature of the second observation was the mean of the other two; now as three or more observations were made at each interval, it was easy to obtain the wished-for temperature as the mean of several determinations. Thus the formulæ deduced for correction of conducting-power for temperature of the alloy Cd Pb_6 were—

From seven observations . . . $\lambda=9{\cdot}287-0{\cdot}032501t+0{\cdot}00006743t^2$.

From three observations . . . $\lambda=9{\cdot}286-0{\cdot}032450t+0{\cdot}00006683t^2$.

Again, those deduced for the alloy Sn_2 Zn were—

From seven observations . . . $\lambda=16{\cdot}876-0{\cdot}065544t+0{\cdot}0001471t^2$,

From three observations . . . $\lambda=16{\cdot}899-0{\cdot}065790t+0{\cdot}0001454t^2$,

where λ represents the conducting-power at $t°$ C.

We have here taken, as in former papers, the conducting-power of a hard-drawn silver wire at 0°=100 as defining our unit. The normal wires were made of german silver, the resistances of which were determined by comparing them with the gold-silver alloy‡, the conducting-power of a hard-drawn wire of which is equal to 15·03 at 0°.

* Philosophical Transactions, 1860, p. 162.

† Ibid. 1862, p. 1.

‡ Philosophical Magazine for February 1861.

Table II. contains the conducting-powers, specific gravities, and equivalents of the metals used for making the alloys. These values are those which have been used in calculating the results given in this paper.

TABLE II.

Metal.	Conducting-power at 0°.	Specific gravity.	Equivalent.
Silver (hard drawn).........	100·00	10·468	108·0
Silver (annealed)	108·57	....	......
Copper (hard drawn)	99·95	8·950	31·7
Gold (hard drawn)	77·96	19·265	197·0
Gold (annealed)	79·33	....	......
Zinc	29·02	7·148	32·6
Cadmium	23·72	8·655	56·0
Palladium (hard drawn)...	18·45	11·500	......
Platinum (hard drawn) ...	17·99	21·400	......
Iron (hard drawn)	16·81	7·790	......
Nickel	13·11	8·50	......
Tin	12·36	7·294	58·0
Thallium	9·16	11·900	......
Lead	8·32	11·376	103·7
Bismuth	1·245	9·822	208·0

Tables III., IV., V., and VI. contain the results obtained with the alloys belonging to the different groups. The alloys marked thus (†) are those which were made and used for former experiments; in all cases, however, fresh wires were made. All the rest have been re-made and analyzed. In Table III. the results are given which were obtained with some alloys made of those metals which, when alloyed with one another, conduct electricity in the ratio of their relative volumes; in Table V. those with some alloys of those metals which, when alloyed with one another, do not conduct electricity in the ratio of their relative volumes, but always in a lower degree than the mean of their volumes; in Table IV. those with some alloys made with the metals belonging to the alloys given in Table III. with those in Table V.; and in Table VI. those with some alloys whose places in the foregoing Tables we have not yet been able to assign.

TABLE III.

1.

†Sn_6Pb, containing 16·04 volumes per cent. of lead.

Length 435·5 millims.; diameter 0·793 millim.

		Reduced to 0°*.
Conducting-power found before heating the wire	11·782 at 13°·7	12·423
Ditto, after being kept at 100° for 1 day	12·052 at 9·3	12·494
Ditto, for 2 days..................	12·088 at 9·1	12·522

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
10°·03	12·043	12·033	+0·010
24·56	11·371	11·381	−0·010
39·27	10·760	10·768	−0·008
55·00	10·168	10·165	+0·003
67·73	9·720	9·716	+0·004
84·93	9·175	9·165	+0·010
98·87	8·757	8·766	−0·009

$\lambda=12{\cdot}510-0{\cdot}0486l9t+0{\cdot}0001087t^2$.

2.

†Sn_4Cd, containing 83·10 volumes per cent. of tin.

Length 285 millims.; diameter 0·417 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	14·259 at 6°·8	14·658
Ditto, after being kept at 100° for 1 day	14·207 at 6·2	14·569
Ditto, for 2 days..................	14·072 at 7·7	14·517

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
8°·72	13·986	13·985	+0·001
25·52	13·089	13·092	−0·003
39·50	12·419	12·423	−0·004
54·96	11·770	11·761	+0·009
69·40	11·218	11·217	+0·001
84·02	10·733	10·740	−0·007
98·85	10·333	10·330	+0·003

$\lambda=14{\cdot}487-0{\cdot}059047t+0{\cdot}0001720t^2$.

* These and all similar values were reduced to 0° as described in the paper "On the Influence of Temperature on the Electric Conducting-power of the Pure Metals," Philosophical Transactions, 1862, p. 10.

Table III. (continued).

3.

†Sn_2Zn, containing 77·71 volumes per cent. of tin.

Length 276·5 millims.; diameter 0·555 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	16·289 at 10°·9	16·991
Ditto, after being kept at 100° for 1 day	15·862 at 15·1	16·815
Ditto, for 2 days	16·201 at 10·9	16·899

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
11°·08	16·188	16·168	+0·020
24·42	15·339	15·363	−0·024
39·27	14·516	14·529	−0·013
54·23	13·759	13·754	+0·005
69·40	13·055	13·037	+0·018
84·11	12·414	12·404	+0·010
96·65	11·899	11·915	−0·016

$\lambda=16{\cdot}876-0{\cdot}065544t+0{\cdot}0001471t^2.$

4.

†$PbSn$, containing 53·41 volumes per cent. of lead.

Length 359 millims.; diameter 0·844 millim.*

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
9°·12	10·073	10·071	+0·002
24·45	9·510	9·511	−0·001
39·73	8·992	8·995	−0·003
55·26	8·509	8·512	−0·003
69·61	8·108	8·103	+0·005
84·36	7·724	7·721	+0·003
98·73	7·382	7·385	−0·003

$\lambda=10{\cdot}423-0{\cdot}039433t+0{\cdot}00008775t^2.$

5.

†$ZnCd_2$, containing 26·06 volumes per cent. of zinc.

Length 577 millims.; diameter 0·629 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	24·774 at 11°·1	25·834
Ditto, after being kept at 100° for 1 day	25·101 at 10·1	26·077
Ditto, for 2 days	24·916 at 10·5	25·924

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
11°·60	24·817	24·796	+0·021
24·28	23·600	23·647	−0·047
39·86	22·322	22·324	−0·002
54·00	21·232	21·215	+0·017
68·90	20·164	20·133	+0·031
83·41	19·167	19·168	−0·001
98·23	18·255	18·272	−0·017

$\lambda=25{\cdot}906-0{\cdot}098065t+0{\cdot}0002072t^2.$

Table III. (continued).

6.

†$SnCd_4$, containing 23·50 volumes per cent. of tin.

Length 512·5 millims.; diameter 0·670 millim.

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
12°·57	21·096	21·086	+0·010
25·55	20·068	20·084	−0·016
40·20	19·033	19·037	−0·004
54·30	18·127	18·113	+0·014
69·33	17·219	17·220	−0·001
80·96	16·589	16·594	−0·005
91·30	16·086	16·084	+0·002

$\lambda=22{\cdot}123-0{\cdot}085159t+0{\cdot}0002082t^2.$

7.

†$CdPb_6$, containing 10·57 vols. per cent. of cadmium.

Length 224 millims.; diameter 0·644 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	9·068 at 6°·1	9·264
Ditto, after being kept at 100° for 1 day	9·490 at 2·5	9·574
Ditto, for 2 days	9·039 at 7·7	9·285
Ditto, for 3 days	8·964 at 10·1	9·285

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
11°·50	8·922	8·922	0·000
25·03	8·516	8·516	0·000
40·35	8·083	8·085	−0·002
54·75	7·710	7·710	0·000
70·00	7·342	7·342	0·000
85·55	7·001	7·000	+0·001
98·57	6·737	6·738	−0·001

$\lambda=9{\cdot}287-0{\cdot}032501t+0{\cdot}00006743t^2.$

Table IV.

1.

†$Pb_{20}Ag$, containing 94·64 volumes per cent. of lead.

Length 372 millims.; diameter 0·704 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	8·508 at 13°·7	8·938
Ditto, after being kept at 100° for 1 day	8·578 at 15·2	9·060
Ditto, for 2 days	8·640 at 14·3	9·096
Ditto, for 3 days	8·731 at 15·7	9·238
Ditto, for 4 days	8·760 at 14·7	9·236

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
10°·47	8·900	8·901	−0·001
24·93	8·459	8·455	+0·004
39·70	8·026	8·031	−0·005
55·03	7·625	7·625	0·000
70·26	7·256	7·256	0·000
85·16	6·933	6·927	+0·006
98·47	6·658	6·662	−0·004

$\lambda=9{\cdot}244-0{\cdot}033467t+0{\cdot}00007360t^2.$

* The reason why here and in some cases in the following Tables no determinations of the effect of heating the wire on its conducting-power are given, is that the wire unfortunately, from some cause or another, became unsoldered after it had been heated to 100° for one or more days.

Table IV. (continued).

2.

†Pb Ag, containing 46·90 volumes per cent. of lead.

Length 267 millims.; diameter 0·584 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	13·009 at 14°·9	13·391
Ditto, after being kept at 100° for 1 day	13·072 at 15·9	13·482
Ditto, for 2 days..................	13·087 at 15·1	13·477

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
14°·10	18·099	13·100	−0·001
24·70	12·841	12·837	+0·004
39·88	12·478	12·477	+0·001
54·61	12·141	12·146	−0·005
70·05	11·818	11·818	0·000
83·88	11·546	11·542	+0·004
99·37	11·250	11·251	−0·001

$\lambda = 13{\cdot}464 - 0{\cdot}26424t + 0{\cdot}00004174t^2$.

3.

Pb Ag_2, containing 30·64 volumes per cent. of lead.

Length 373 millims.; diameter 0·634 millim.

		Reduced to 0°.
Conducting-power found after heating the wire for 2 days...	21·186 at 16°·1	21·874
Ditto, for 3 days..................	21·160 at 16·5	21·863

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
15°·82	21·191	21·190	+0·001
24·96	20·811	20·813	−0·002
39·48	20·236	20·232	+0·004
54·17	19·669	19·669	0·000
69·78	19·089	19·098	−0·009
84·27	18·602	18·593	+0·009
100·00	18·069	18·071	−0·002

$\lambda = 21{\cdot}866 - 0{\cdot}043636t + 0{\cdot}00005686t^2$.

4.

†Sn_{12} Au, containing 90·32 volumes per cent. of tin.

		Reduced to 0°.
Conducting-power found before heating the wire	7·9495 at 11°·8	8·2418
Ditto, after being kept at 100° for 1 day	7·9479 at 13·0	8·2702

T.	Conducting-power.
14°·0	7·9224
57·0	6·9935
100·0	6·2676

$\lambda = 8{\cdot}2687 - 0{\cdot}025501t + 0{\cdot}00005490t^2$.

Table IV. (continued).

5.

†Sn_5 Au, containing 79·54 volumes per cent. of tin.

Length 222 millims.; diameter 0·599 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	4·8386 at 14°·3	5·0427
Ditto, after being kept at 100° for 1 day	4·8432 at 14·6	5·0518
Ditto, for 2 days..................	4·8741 at 13·0	5·0608

T.	Conducting-power.
14°·0	4·8593
57·0	4·3212
100·0	3·9009

$\lambda = 5{\cdot}0599 - 0{\cdot}014776t + 0{\cdot}00003186t^2$.

6.

Tin-copper alloy, containing 93·57 volumes per cent. of tin.

Length 274·5 millims; diameter 0·667 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	11·264 at 18°·1	12·034
Ditto, after being kept at 100° for 1 day	11·498 at 16·9	12·231
Ditto, for 2 days..................	11·445 at 18·3	12·237
Ditto, for 3 days..................	11·549 at 16·3	12·259
Ditto, for 4 days..................	11·571 at 16·3	12·282
Ditto, for 5 days..................	11·558 at 17·1	12·304

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
15°·58	11·622	11·618	+0·004
24·70	11·242	11·242	0·000
38·91	10·679	10·688	−0·009
54·96	10·109	10·111	−0·002
70·29	9·615	9·609	+0·006
85·68	9·160	9·152	+0·608
99·40	8·777	8·784	−0·007

$\lambda = 12{\cdot}299 - 0{\cdot}045304t + 0{\cdot}00009997t^2$.

7.

Tin-copper alloy, containing 83·60 volumes per cent. of tin.

Length 201 millims.; diameter 0·581 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	12·119 at 15°·7	12·764
Ditto, after being kept at 100° for 1 day	12·264 at 15·3	12·900
Ditto, for 2 days..................	12·389 at 15·3	13·031
Ditto, for 3 days..................	12·420 at 14·7	13·038
Ditto, for 4 days..................	12·384 at 15·7	13·043

T.	Conducting-power.		Difference.
	Observed	Calculated.	
8°·27	12·688	12·689	−0·001
25·28	12·009	12·002	+0·007
39·43	11·460	11·470	−0·010
54·31	10·943	10·949	−0·006
70·13	10·444	10·437	+0·007
84·18	10·032	10·022	+0·010
99·28	9·607	9·614	−0·007

$\lambda = 13{\cdot}042 - 0{\cdot}043382t + 0{\cdot}00008924t^2$.

TABLE IV. (continued).

8.

Tin-copper alloy, containing 14·91 vols. per cent. of tin.

Length 141 millims.; diameter 0·501 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	8·7481 at 15°·5	8·8223
Ditto, after being kept at 100° for 1 day	8·8372 at 16·5	8·9170
Ditto, for 2 days	8·8451 at 17·3	8·9288
Ditto, for 3 days	8·8441 at 17·0	8·9264

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
16°·58	8·8565	8·8560	+0·0005
34·85	8·7687	8·7692	−0·0005
56·33	8·6684	8·6693	−0·0009
77·40	8·5753	8·5737	+0·0016
99·48	8·4754	8·4760	−0·0006

$$\lambda=8\cdot9364-0\cdot0048890t+0\cdot000002626t^2.$$

9.

Tin-copper alloy, containing 12·35 vols. per cent. of tin.

Length 429 millims.; diameter 0·627 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	10·037 at 17°·9	10·154
Ditto, after being kept at 100° for 1 day	10·076 at 18·2	10·196
Ditto, for 2 days	10·084 at 17·2	10·197
Ditto, for 3 days	10·084 at 16·6	10·193

T.	Conducting-power.
11°·0	10·1386
55·5	9·8710
100·0	9·6526

$$\lambda=10\cdot212-0\cdot0068043t+0\cdot00001210t^2.$$

10.

Tin-copper alloy, containing 11·61 vols. per cent. of tin.

Length 322·5 millims.; diameter 0·524 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	12·003 at 12°·1	12·102
Ditto, after being kept at 100° for 1 day	12·069 at 11·5	12·165
Ditto, for 2 days	12·083 at 12·5	12·188
Ditto, for 3 days	12·070 at 14·3	12·190

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
15°·43	12·058	12·057	+0·001
23·40	11·990	11·991	−0·001
40·35	11·852	11·853	−0·001
54·75	11·737	11·736	+0·001
69·78	11·619	11·617	+0·002
84·66	11·499	11·500	−0·001
98·70	11·391	11·391	0·000

$$\lambda=12\cdot186-0\cdot008468t+0\cdot000003700t^2.$$

11.

Tin-copper alloy, containing 6·02 vols. per cent. of tin.

Length 210 millims.; diameter 0·456 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	19·382 at 15°·5	19·682
Ditto, after being kept at 100° for 1 day	19·517 at 15·5	19·819
Ditto, for 2 days	19·496 at 16·4	19·816

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
17°·23	19·484	19·484	0·000
24·03	19·355	19·354	+0·001
40·03	19·050	19·052	−0·002
55·47	18·771	18·769	+0·002
69·70	18·511	18·513	−0·002
83·16	18·279	18·276	+0·003
98·87	18·004	18·006	−0·002

$$\lambda=19\cdot820-0\cdot019729t+0\cdot00001397t^2.$$

12.

Tin-copper alloy, containing 1·41 vol. per cent. of tin.

Length 599 millims.; diameter 0·449 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	60·105 at 14°·5	62·463
Ditto, after being kept at 100° for 1 day	60·827 at 12·5	62·881
Ditto, for 2 days	60·687 at 14·1	63·001
Ditto, for 3 days	60·579 at 15·1	63·055
Ditto, for 4 days	60·690 at 14·3	63·038

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
15°·53	60·470	60·455	+0·015
24·68	59·011	59·029	−0·018
39·03	56·897	56·900	−0·003
54·98	54·681	54·686	−0·005
68·73	52·924	52·906	+0·018
84·25	51·036	51·041	−0·005
99·70	49·334	49·336	−0·002

$$\lambda=62\cdot997-0\cdot16856t+0\cdot0003163t^2.$$

13.

Tin-silver alloy, containing 96·52 vols. per cent. of tin.

Length 304 millims.; diameter 0·478 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	11·646 at 16°·3	12·390
Ditto, after being kept at 100° for 1 day	11·686 at 16·3	12·433
Ditto, for 2 days	11·685 at 17·0	12·464
Ditto, for 3 days	11·668 at 17·6	12·475

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
11°·12	11·983	11·971	+0·012
24·90	11·353	11·364	−0·011
39·40	10·751	10·768	−0·017
54·60	10·193	10·189	+0·004
69·81	9·676	9·657	+0·019
84·88	9·178	9·177	+0·001
99·68	8·743	8·751	−0·008

$$\lambda=12\cdot488-0\cdot047691t+0\cdot0001023t^2.$$

Table IV. (continued).

14.

Tin-silver alloy, containing 75·51 vols. per cent. of tin.

Length 273 millims.; diameter 0·467 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	12·982 at 17°·6	13·866
Ditto, after being kept at 100° for 1 day	13·054 at 17·1	13·917
Ditto, for 2 days	13·334 at 16·5	14·184
Ditto, for 3 days	13·415 at 15·5	14·217
Ditto, for 4 days	13·402 at 16·5	14·256

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
11°·53	13·651	13·646	+0·005
25·51	12·955	12·958	−0·003
40·26	12·283	12·283	0·000
53·86	11·700	11·708	−0·008
69·58	11·099	11·099	0·000
84·98	10·572	10·561	+0·011
99·48	10·103	10·108	−0·005

$\lambda = 14{\cdot}250 - 0{\cdot}053772t + 0{\cdot}0001219t^2$.

15.

Zinc-copper alloy, containing 42·06 vols. per cent. of zinc.

Length 296·6 millims.; diameter 0·516 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	21·356 at 14°·8	21·793
Ditto, after being kept at 100° for 1 day	21·701 at 12·9	22·088
Ditto, for 2 days	21·873 at 13·1	22·269
Ditto, for 3 days	21·824 at 14·9	22·273

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
15°·72	21·807	21·801	+0·006
23·75	21·562	21·564	−0·002
39·28	21·116	21·118	−0·002
54·38	20·693	20·698	−0·005
69·31	20·300	20·297	+0·003
84·63	19·897	19·898	−0·001
99·43	19·527	19·526	+0·001

$\lambda = 22{\cdot}274 - 0{\cdot}030601t + 0{\cdot}00002980t^2$.

16.

Zinc-copper alloy, containing 29·45 vols. per cent. of zinc.

Length 190 millims.; diameter 0·381 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	21·235 at 17°·4	21·708
Ditto, after being kept at 100° for 1 day	21·424 at 15·9	21·859
Ditto, for 2 days	21·597 at 15·9	22·036
Ditto, for 3 days	21·625 at 15·9	22·065
Ditto, for 4 days	21·720 at 12·8	22·075

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
13°·47	21·704	21·702	+0·002
24·07	21·413	21·416	−0·003
39·21	21·020	21·017	+0·003
53·65	20·647	20·647	0·000
69·03	20·268	20·269	−0·001
83·71	19·915	19·916	−0·001
98·97	19·565	19·564	+0·001

$\lambda = 22{\cdot}076 - 0{\cdot}028100t + 0{\cdot}00002745t^2$.

Table IV. (continued).

17.

Zinc-copper alloy, containing 23·61 vols. per cent. of zinc.

Length 365 millims.; diameter 0·379 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	27·784 at 13°·0	28·298
Ditto, after being kept at 100° for 1 day	27·754 at 14·9	28·343
Ditto, for 2 days	27·738 at 15·3	28·342

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
15°·97	27·719	27·714	+0·005
23·80	27·408	27·412	−0·004
39·28	26·828	26·829	−0·001
54·82	26·259	26·262	−0·003
68·66	25·777	25·772	+0·005
83·75	25·258	25·256	+0·002
98·22	24·774	24·776	−0·002

$\lambda = 28{\cdot}345 - 0{\cdot}040104t + 0{\cdot}00003839t^2$.

18.

Zinc-copper alloy, containing 10·88 vols. per cent. of zinc.

Length 449 millims.; diameter 0·448 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	45·545 at 14°·8	46·934
Ditto, after being kept at 100° for 1 day	45·807 at 14·0	47·128
Ditto, for 2 days	45·896 at 14·6	47·276
Ditto, for 3 days	45·971 at 13·7	47·268

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
14°·33	45·912	45·912	0·000
23·71	45·059	45·056	+0·003
39·80	43·638	43·648	−0·010
54·33	42·442	42·440	+0·002
69·48	41·246	41·245	+0·001
84·38	40·145	40·134	+0·011
98·95	39·100	39·109	−0·009

$\lambda = 47{\cdot}267 - 0{\cdot}096627t + 0{\cdot}0001433t^2$.

19.

Zinc-copper alloy, containing 5·03 vols. per cent. of zinc

Length 642 millims.; diameter 0·479 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	58·152 at 15°·3	60·376
Ditto, after being kept at 100° for 1 day	58·546 at 14·3	60·637
Ditto, for 2 days	58·665 at 14·0	60·716
Ditto, for 3 days	58·598 at 14·3	60·691

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
15°·17	58·522	58·494	+0·028
23·57	57·277	57·301	−0·024
40·03	55·071	55·093	−0·022
54·91	53·211	53·213	−0·002
67·88	51·679	51·664	+0·015
84·15	49·856	49·839	+0·017
99·45	48·228	48·243	−0·015

$\lambda = 60{\cdot}697 - 0{\cdot}14995t + 0{\cdot}0002486t^2$.

TABLE V.

1.

Gold-copper alloy, containing 98·63 volumes per cent. of gold (hard drawn).

Length 1121·5 millims.; diameter 0·582 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	53·694 at 16°·8	56·122
Ditto, after being kept at 100° for 1 day	53·796 at 16·5	56·184
Ditto, for 2 days	53·835 at 16·7	56·268

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
15°·52	53·972	53·980	−0·008
25·10	52·676	52·653	+0·023
39·74	50·684	50·715	−0·031
55·66	48·739	48·740	−0·001
69·83	47·106	47·092	+0·014
85·00	45·451	45·443	+0·008
95·35	43·986	43·994	−0·008

$\lambda = 56{\cdot}232 - 0{\cdot}14916t + 0{\cdot}0002616t^2$.

2.

Gold-copper alloy, containing 81·66 volumes per cent. of gold (hard drawn).

Length 450 millims.; diameter 0·501 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	15·919 at 13°·6	16·083
Ditto, after being kept at 100° for 1 day	15·935 at 11·1	16·068
Ditto, for 2 days	15·895 at 12·2	16·041
Ditto, for 3 days	15·894 at 11·0	16·026
Ditto, for 4 days	15·887 at 11·4	16·024

T.	Conducting-power.
12°·0	15·880
56·0	15·356
100·0	14·837

$\lambda = 16{\cdot}024 - 0{\cdot}011997t + 0{\cdot}000001291t^2$.

3.

Gold-silver alloy, containing 79·86 volumes per cent. of gold (hard drawn).

Length 605·7 millims.; diameter 0·704 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	21·010 at 11°·7	21·279
Ditto, after being kept at 100° for 1 day	21·038 at 10·8	21·286
Ditto, for 2 days	21·072 at 10·4	21·311
Ditto, for 3 days	21·066 at 10·2	21·301

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
11°·45	21·013	21·030	+0·001
26·04	20·698	20·701	−0·003
40·04	20·391	20·392	−0·001
55·26	20·065	20·064	+0·001
67·73	19·806	19·802	+0·004
84·13	19·463	19·464	−0·001
98·45	19·175	19·176	−0·001

$\lambda = 21{\cdot}293 - 0{\cdot}023166t + 0{\cdot}00001691t^2$.

TABLE V. (continued).

4.

Gold-silver alloy, containing 79·86 volumes per cent. of gold (annealed*).

Length 596 millims.; diameter 0·704 millim.

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
7°·64	21·342	21·341	+0·001
25·27	20·920	20·924	−0·001
40·71	20·570	20·572	−0·002
54·61	20·265	20·264	+0·001
70·35	19·930	19·928	+0·002
85·25	19·622	19·622	0·000
99·50	19·338	19·339	−0·001

$\lambda = 21{\cdot}527 - 0{\cdot}024475t + 0{\cdot}00002500t^2$.

5.

Gold-silver alloy, containing 19·86 volumes per cent. of gold (hard drawn).

Length 161·5 millims.; diameter 0·351 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	21·835 at 11°·7	22·062
Ditto, after being kept at 100° for 1 day	21·872 at 11·8	22·101
Ditto, for 2 days	21·841 at 12·5	22·083

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
13°·02	21·838	21·833	+0·005
23·90	21·620	21·625	−0·005
38·03	21·355	21·359	−0·004
54·42	21·158	21·056	+0·002
68·95	20·795	20·794	+0·001
82·37	20·557	20·555	+0·002
98·15	20·279	20·280	−0·001

$\lambda = 22{\cdot}085 - 0{\cdot}019538t + 0{\cdot}00001173t^2$.

6.

Gold-silver alloy, containing 19·86 volumes per cent. of gold (annealed*).

Length 161·5 millims.; diameter 0·351 millim.

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
14°·95	21·829	21·827	+0·002
24·56	21·637	21·640	−0·003
40·33	21·335	21·337	−0·002
55·38	21·059	21·055	+0·004
69·06	20·806	20·805	+0·001
84·48	20·527	20·528	−0·001
97·53	20·299	20·300	−0·001

$\lambda = 22{\cdot}125 - 0{\cdot}020097t + 0{\cdot}00001419t^2$.

* The conducting-power of these wires did not alter after being kept at 100° for one day.

Table V. (continued).

7.

Gold-copper alloy, containing 19·17 volumes per cent. of gold (hard drawn).

Length 534 millims.; diameter 0·550 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	20·300 at 12°·2	20·504
Ditto, after being kept at 100° for 1 day	20·296 at 12·0	20·517
Ditto, for 2 days	20·287 at 12·4	20·505

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
13°·40	20·272	20·278	−0·006
24·38	20·088	20·088	0·000
40·01	19·838	19·824	+0·014
55·03	19·569	19·573	−0·004
70·11	19·325	19·328	−0·003
84·98	19·088	19·092	−0·004
99·87	18·865	18·861	+0·004

$\lambda=20·513-0·017718t+0·00091170t^2$.

8.

Gold-copper alloy, containing 0·71 volume per cent. of gold (hard drawn).

Length 1049 millims.; diameter 0·366 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	79·884 at 15°·3	84·008
Ditto, after being kept at 100° for 1 day	80·389 at 14·3	84·264
Ditto, for 2 days	80·014 at 15·5	84·200
Ditto, for 3 days	79·844 at 16·6	84·322

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
17°·27	79·709	79·670	+0·039
23·98	77·952	77·962	−0·010
39·55	74·154	74·212	−0·058
54·26	70·294	70·913	−0·019
69·29	67·920	67·879	+0·041
83·86	65·213	65·175	+0·038
98·78	62·645	62·677	−0·032

$\lambda=84·322-0·27999t+0·0006162t^2$.

9.

Platinum-silver alloy, containing 19·65 volumes per cent. of platinum (hard drawn).

Length 169 millims.; diameter 0·518 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	6·6565 at 18°·0	6·6960
Ditto, after being kept at 100° for 1 day	6·0616 at 17·9	6·7008
Ditto, for 2 days	6·6654 at 17·2	6·7031

T.	Conducting-power.
8°·27	6·6850
54·00	6·5876
99·90	6·4957

$\lambda=6·7032-0·0022167t+0·000001394t^2$.

Table V. (continued).

10.

Platinum-silver alloy, containing 5·05 volumes per cent. of platinum (hard drawn).

Length 708 millims.; diameter 0·626 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	17·812 at 15°·9	18·031
Ditto, after being kept at 100° for 1 day	17·801 at 17·1	18·036

T.	Conducting-power.
9°·0	17·920
54·5	17·319
100·0	16·767

$\lambda=18·045-0·013960t+0·00001183t^2$.

11.

Platinum-silver alloy, containing 2·51 volumes per cent. of platinum (hard drawn).

Length 381·5 millims.; diameter 0·451 millim.

T.	Conducting-power.
12°·0	31·173
56·0	29·550
100·0	28·068

$\lambda=31·640-0·039363t+0·00003642t^2$.

12.

Palladium-silver alloy, containing 23·28 volumes per cent. of palladium (hard drawn).

Length 520 millims.; diameter 0·802 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	8·4936 at 10°·0	8·5214
Ditto, after being kept at 100° for 1 day	8·5147 at 10·0	8·5426
Ditto, for 2 days	8·5052 at 9·1	8·5305
Ditto, for 3 days	8·4918 at 8 6	8·5157
Ditto, for 4 days	8·4868 at 10·0	8·5146

T.	Conducting-power.
11°·0	8·4846
55·5	8·3577
100·0	8·2256

$\lambda=8·5152-0·0027644t-0·000001313t^2$.

13.

Copper-silver alloy, containing 98·35 volumes per cent. of copper (hard drawn).

Length 1198 millims.; diameter 0·572 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	86·674 at 9°·5	89·544
Ditto, after being kept at 100° for 1 day	88·210 at 6·5	90·202
Ditto, for 2 days	87·336 at 9·3	90·165

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
10°·48	86·919	86·846	+0·073
25·27	82·583	82·634	−0·051
39·57	78·763	78·861	−0·098
53·96	75·317	75·361	−0·044
69·73	72·007	71·868	+0·139
85·12	68·875	68·802	+0·073
98·35	66·348	66·442	−0·094

$\lambda=90·021-0·31050t+0·0007193t^2$.

TABLE V. (continued).

14.

Copper-silver alloy, containing 95·17 volumes per cent. of copper (hard drawn).

Length 929 millims.; diameter 0·489 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	78·165 at 16°·0	82·300
Ditto, after being kept at 100° for 1 day	78·286 at 14·3	81·981
Ditto, for 2 days	78·102 at 15·9	82·207
Ditto, for 3 days	77·666 at 17·8	82·245

T.	Conducting-power. Observed.	Conducting-power. Calculated.	Difference.
15°·43	78·226	78·219	+0·007
24·26	76·066	76·059	+0·001
39·16	72·601	72·616	−0·015
54·62	69·301	69·312	−0·011
69·48	66·406	66·393	+0·013
83·53	63·885	63·866	+0·019
99·00	61·319	61·343	−0·014

$\lambda=82\cdot207-0\cdot26728t+0\cdot0005711t^2$.

15.

Copper-silver alloy, containing 77·64 volumes per cent. of copper (hard drawn).

Length 623 millims.; diameter 0·374 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	66·807 at 14°·6	69·811
Ditto, after being kept at 100° for 1 day	66·601 at 17·3	70·158
Ditto, for 2 days	66·550 at 17·2	70·084
Ditto, for 3 days	66·707 at 17·0	70·208
Ditto, for 4 days	66·694 at 17·6	70·319

T.	Conducting-power. Observed.	Conducting-power. Calculated.	Difference.
15°·15	67·155	67·192	−0·037
24·21	65·433	65·410	+0·023
39·48	62·583	62·565	+0·018
54·90	59·873	59·894	−0·021
69·48	57·557	57·556	+0·001
84·28	55·375	55·365	+0·001
99·90	53·259	53·262	−0·003

$\lambda=70\cdot328-0\cdot21351t+0\cdot0004271t^2$.

16.

Copper-silver alloy, containing 46·67 volumes per cent. of copper (hard drawn).

Length 1256 millims.; diameter 0·437 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	72·036 at 14°·2	74·940
Ditto, after being kept at 100° for 1 day	73·170 at 14·6	76·204
Ditto, for 2 days	73·653 at 12·6	76·284

T.	Conducting-power.
13°·0	73·529
56·5	65·449
100·0	58·894

$\lambda=76\cdot240-0\cdot21375t+0\cdot0004030t^2$.

TABLE V. (continued).

17.

Copper-silver alloy, containing 8·25 volumes per cent. of copper (hard drawn).

Length 2328 millims.; diameter 0·525 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	78·323 at 9°·0	80·284
Ditto, after being kept at 100° for 1 day	78·855 at 8·5	80·718
Ditto, for 2 days	78·398 at 10·2	80·626

T.	Conducting-power.
12°·0	87·015
56·0	69·301
100·0	61·949

$\lambda=80\cdot628-0\cdot22196t+0\cdot0003518t^2$.

18.

Copper-silver alloy, containing 1·53 volume per cent. of copper (hard drawn).

Length 2139 millims.; diameter 0·542 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	94·554 at 9°·8	97·708
Ditto, after being kept at 100° for 1 day	95·314 at 9·0	98·231
Ditto, for 2 days	94·968 at 9·9	98·168

T.	Conducting-power.
10°·0	94·940
55·0	82·126
100·0	72·146

$\lambda=98\cdot172-0\cdot033024t+0\cdot0006998t^2$.

19.

Iron-gold alloy, containing 27·93 volumes per cent. of iron (hard drawn).

Length 145 millims.; diameter 0·758 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	2·5815 at 14°·6	2·7160
Ditto, after being kept at 100° for 1 day	2·6193 at 14·4	2·7539
Ditto, for 2 days	2·6309 at 14·2	2·7641
Ditto, for 3 days	2·6286 at 14·4	2·7636

T.	Conducting-power.
15°·0	2·6239
57·5	2·2732
100·0	1·9926

$\lambda=2\cdot7645-0\cdot0096586t+0\cdot00001940t^2$.

		Reduced to 0°.
The conducting-power of a second wire was found	2·6177 at 14°·6	2·7451

Table V. (continued).

20.

Iron-gold alloy, containing 21·18 volumes per cent. of iron (hard drawn).

Length 184 millims.; diameter 0·943 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	1·9299 at 14°·6	2·0121
Ditto, after being kept at 100° for 1 day	1·9981 at 10·8	2·0614
Ditto, for 2 days	1·9866 at 13·2	2·0621

T.	Conducting-power.
14°·0	1·9822
57·0	1·7951
100·7	1·7010

$$\lambda=2{\cdot}0632-0{\cdot}0061367t+0{\cdot}00002515t^2.$$

		Reduced to 0°.
The conducting-power of a second wire was found	1·8745 at 17°·2	1·9681

21.

Iron-gold alloy, containing 10·96 volumes per cent. of iron (hard drawn).

Length 226 millims.; diameter 0·470 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	2·3450 at 15°·6	2·3624
Ditto, after being kept at 100° for 1 day	2·3549 at 13·8	2·3704
Ditto, for 2 days	2·3585 at 10·4	2·3703

T.	Conducting-power.
12°·0	2·3573
56·0	2·3138
100·0	2·2798

$$\lambda=2{\cdot}3708-0{\cdot}0011555t+0{\cdot}0000002454t^2.$$

		Reduced to 0°.
The conducting-power of a second wire was found	2·2397 at 17°·2	2·2580

22.

Iron-copper alloy, containing 0·46 volume per cent. of iron (hard drawn).

Length 573·5 millims.; diameter 0·358 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	38·315 at 9°·0	38·852
Ditto, after being kept at 100° for 1 day	39·055 at 9·4	39·626
Ditto, for 2 days	39·124 at 10·4	39·758
Ditto, for 3 days	39·241 at 10·0	39·852
Ditto, for 4 days	39·313 at 11·0	39·986
Ditto, for 5 days	39·384 at 8·8	39·887

T.	Conducting-power.
10°·0	39·283
55·0	36·739
100·0	34·533

$$\lambda=39{\cdot}894-0{\cdot}061958t+0{\cdot}00008346t^2.$$

Table VI.

1.

†Phosphorus-copper, containing 2·5 per cent. by weight of phosphorus (hard drawn).

Length 124 millims.; diameter 0·355 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	7·2993 at 12°·6	7·3432
Ditto, after being kept at 100° for 1 day	7·3287 at 12·3	7·3717
Ditto, for 2 days	7·3424 at 13·6	7·3901

T.	Conducting-power. Observed.	Conducting-power. Calculated.	Difference.
14°·52	7·3395	7·3391	+0·0004
34·22	7·2696	7·2708	−0·0012
56·25	7·1963	7·1954	+0·0009
77·35	7·1243	7·1241	+0·0002
99·08	7·0515	7·0517	−0·0002

$$\lambda=7{\cdot}3900-0{\cdot}0035194t+0{\cdot}000001062t^2.$$

2.

†Phosphorus-copper, containing 0·95 per cent. by weight of phosphorus (hard drawn).

Length 265·5 millims.; diameter 0·396 millim.

T.	Conducting-power. Observed.	Conducting-power. Calculated.	Difference.
11°·05	23·028	23·032	−0·004
24·50	22·637	22·635	+0·002
39·72	22·209	22·203	+0·006
54·96	21·785	21·787	−0·002
69·48	21·407	21·408	−0·001
84·92	21·017	21·023	−0·006
99·83	20·673	20·668	+0·005

$$\lambda=23{\cdot}368-0{\cdot}030873t+0{\cdot}00003836t^2.$$

3.

†Arsenic-copper, containing 5·4 per cent. by weight of arsenic (hard drawn).

Length 225 millims.; diameter 0·289 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	6·3518 at 9°·3	6·3739
Ditto, after being kept at 100° for 1 day	6·3780 at 8·4	6·3980
Ditto, for 2 days	6·3800 at 7·9	6·3988

T.	Conducting-power. Observed.	Conducting-power. Calculated.	Difference.
10°·52	6·3742	6·3738	+0·0004
31·80	6·3230	6·3235	−0·0005
54·20	6·2707	6·2713	−0·0006
75·58	6·2232	6·2220	+0·0012
98·05	6·1703	6·1708	−0·0005

$$\lambda=6{\cdot}3989-0{\cdot}0023880t+0{\cdot}0000006331t^2.$$

TABLE VI. (continued).

4.

†Arsenic-copper, containing 2·8 per cent. by weight of arsenic (hard drawn).

Length 547 millims.; diameter 0·431 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	12·2980 at 8°·9	12·3787
Ditto, after being kept at 100° for 1 day	12·2648 at 9·5	12·3507
Ditto, for 2 days	12·2369 at 11·9	12·3443

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
13°·60	12·1933	12·1930	+0·0003
24·75	12·0937	12·0945	−0·0008
39·78	11·9648	11·9635	+0·0013
54·72	11·8364	11·8358	+0·0006
69·11	11·7152	11·7151	+0·0001
84·72	11·5837	11·5867	−0·0030
100·28	11·4631	11·4614	+0·0017

$\lambda=12{\cdot}3156-0{\cdot}0090694t+0{\cdot}000005496t^2$.

5.

†Arsenic-copper, containing traces of arsenic (hard drawn).

Length 381 millims.; diameter 0·364 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	58·680 at 16°·4	61·255
Ditto, after being kept at 100° for 1 day	58·924 at 14·5	61·207
Ditto, for 2 days	59·286 at 12·7	61·295
Ditto, for 3 days	59·013 at 14·1	61·236

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
14°·65	58·948	58·931	+0·017
23·85	57·533	57·546	−0·013
39·95	55·226	55·244	−0·018
54·48	53·298	53·299	−0·001
69·26	51·464	51·448	+0·016
83·47	49·801	49·790	+0·011
98·62	48·141	48·154	−0·013

$\lambda=61{\cdot}238-0{\cdot}16183t+0{\cdot}00002957t^2$.

Tables VII., VIII., IX., and X. contain (1) the values found in a former research*, reduced to 0° with the help of the formula given in the above Tables for some of the alloys (column A.), (2) the values taken from the above Tables, namely, the first observed conducting-power reduced to 0° (column B.), and (3) the formulæ for the correction of the conducting-power for temperature, taking the mean of the values in the columns A. and B. as the conducting-power at 0°.

TABLE VII.

Alloy.	Volumes per cent.	Conducting-power.		Formulæ for the correction of the conducting-power for temperature.
		A.	B.	
Sn_6 Pb	83·96 of Sn	11·582	12·423	$\lambda=12{\cdot}002-0{\cdot}046645t+0{\cdot}0001042t^2$
Sn_4 Cd	83·10 of Sn	14·459	14·658	$\lambda=14{\cdot}558-0{\cdot}059337t+0{\cdot}0001728t^2$
Sn_2 Zn	77·71 of Sn	16·504	16·991	$\lambda=16{\cdot}747-0{\cdot}065044t+0{\cdot}0001460t^2$
Pb Sn	53·41 of Pb	9·855	10·423	$\lambda=10{\cdot}139-0{\cdot}038358t+0{\cdot}00008536t^2$
Zn Cd_2	26·06 of Zn	25·405	25·834	$\lambda=25{\cdot}619-0{\cdot}096978t+0{\cdot}0002049t^2$
Sn Cd_4	23·50 of Sn	21·194	22·123	$\lambda=21{\cdot}658-0{\cdot}083368t+0{\cdot}0002038t^2$
Cd Pb_6	10·57 of Cd	9·047	9·264	$\lambda=9{\cdot}155-0{\cdot}032041t+0{\cdot}00006647t^2$

TABLE VIII.

Alloy.	Volumes per cent.	Conducting-power.		Formulæ for the correction of the conducting-power for temperature.
		A.	B.	
Lead-silver	94·64 of Pb	8·823	8·938	$\lambda=8{\cdot}880-0{\cdot}032149t+0{\cdot}00007070t^2$
Lead-silver	46·90 of Pb	12·071	13·391	$\lambda=12{\cdot}731-0{\cdot}024986t+0{\cdot}00003947t^2$
Lead-silver	30·64 of Pb	....	21·874	$\lambda=21{\cdot}874-0{\cdot}043652t+0{\cdot}00005687t^2$
Tin-gold	90·32 of Sn	8·2418	....	$\lambda=8{\cdot}2418-0{\cdot}025418t+0{\cdot}00005472t^2$
Tin-gold	79·54 of Sn	4·5500	5·0427	$\lambda=4{\cdot}7963-0{\cdot}014006t+0{\cdot}00003020t^2$
Tin-copper (hard drawn)	93·57 of Sn	....	12·034	$\lambda=12{\cdot}034-0{\cdot}044328t+0{\cdot}00009781t^2$
Tin-copper (hard drawn)	83·60 of Sn	....	12·764	$\lambda=12{\cdot}764-0{\cdot}042457t+0{\cdot}00008734t^2$
Tin-copper (hard drawn)	14·91 of Sn	....	8·823	$\lambda=8{\cdot}8223-0{\cdot}0048266t+0{\cdot}000002593t^2$
Tin-copper (hard drawn)	12·35 of Sn	....	10·154	$\lambda=10{\cdot}154-0{\cdot}0067656t+0{\cdot}00001203t^2$
Tin-copper (hard drawn)	11·61 of Sn	....	12·102	$\lambda=12{\cdot}102-0{\cdot}0083587t+0{\cdot}000003674t^2$
Tin-copper (hard drawn)	6·02 of Sn	19·750	19·682	$\lambda=19{\cdot}716-0{\cdot}019626t+0{\cdot}00001390t^2$
Tin-copper (hard drawn)	1·41 of Sn	....	62·463	$\lambda=62{\cdot}463-0{\cdot}16713t+0{\cdot}0003136t^2$
Tin-silver	96·52 of Sn	12·378	12·390	$\lambda=12{\cdot}384-0{\cdot}047293t+0{\cdot}0001014t^2$
Tin-silver	75·51 of Sn	13·547	13·866	$\lambda=13{\cdot}706-0{\cdot}051720t+0{\cdot}0001172t^2$
Zinc-copper (hard drawn)	42·06 of Zn	....	21·793	$\lambda=21{\cdot}793-0{\cdot}029939t+0{\cdot}00002916t^2$
Zinc-copper (hard drawn)	29·45 of Zn	....	21·708	$\lambda=21{\cdot}708-0{\cdot}027632t+0{\cdot}00002698t^2$
Zinc-copper (hard drawn)	23·61 of Zn	....	28·298	$\lambda=28{\cdot}298-0{\cdot}040039t+0{\cdot}00003832t^2$
Zinc-copper (hard drawn)	10·88 of Zn	....	46·934	$\lambda=46{\cdot}934-0{\cdot}095947t+0{\cdot}0001423t^2$
Zinc-copper (hard drawn)	5·03 of Zn	....	60·376	$\lambda=60{\cdot}376-0{\cdot}14916t+0{\cdot}0002473t^2$

* Philosophical Transactions, 1860, p. 166.

TABLE IX.

Alloy.	Volumes per cent.	Conducting-power. A.	Conducting-power. B.	Formulæ for the correction of the conducting-power for temperature.
Gold-copper (hard drawn)	98·63 of Au	....	56·122	$\lambda=56{\cdot}122-0{\cdot}14887t+0{\cdot}0002611t^2$
Gold-copper (hard drawn)	81·66 of Au	....	16·083	$\lambda=16{\cdot}083-0{\cdot}012041t+0{\cdot}000001296t^2$
Gold-silver (hard drawn)	79·86 of Au	21·393	21·279	$\lambda=21{\cdot}335-0{\cdot}023212t+0{\cdot}00001694t^2$
Gold-silver (annealed)...............	79·86 of Au	....	21·527	$\lambda=21{\cdot}584^*-0{\cdot}024539t+0{\cdot}00002506t^2$
Gold-silver (hard drawn)	52·08 of Au	15·030	....	$\lambda=15{\cdot}030-0{\cdot}010120t+0{\cdot}000003697t^2$
Gold-silver (annealed)...............	52·08 of Au	15·080	....	$\lambda=15{\cdot}080-0{\cdot}010864t+0{\cdot}000007457t^2$
Gold-silver (hard drawn)	19·86 of Au	21·305	22·062	$\lambda=21{\cdot}684-0{\cdot}019185t+0{\cdot}00001152t^2$
Gold-silver (annealed)...............	19·86 of Au	....	22·125	$\lambda=21{\cdot}746^*-0{\cdot}019753t+0{\cdot}00001395t^2$
Gold-copper (hard drawn)	19·17 of Au	....	20·514	$\lambda=20{\cdot}514-0{\cdot}017718t+0{\cdot}00001170t^2$
Gold-copper (hard drawn)	0·71 of Au	....	84·008	$\lambda=84{\cdot}008-0{\cdot}27895t+0{\cdot}0006139t^2$
Platinum-silver (hard drawn) ...	19·65 of Pt	....	6·6960	$\lambda=6{\cdot}6960-0{\cdot}0022143t+0{\cdot}000001393t^2$
Platinum-silver (hard drawn) ...	5·05 of Pt	....	18·031	$\lambda=18{\cdot}031-0{\cdot}013949t+0{\cdot}00001182t^2$
Platinum-silver (hard drawn) ...	2·51 of Pt	....	31·640	$\lambda=31{\cdot}640-0{\cdot}039363t+0{\cdot}00003642t^2$
Palladium-silver (hard drawn) ...	23·28 of Pd	....	8·5214	$\lambda=8{\cdot}5214-0{\cdot}002764t-0{\cdot}000001314t^2$
Copper-silver (hard drawn)†	98·35 of Cu	....	89·544	$\lambda=89{\cdot}544-0{\cdot}30886t+0{\cdot}0007155t^2$
Copper-silver (hard drawn)†	95·17 of Cu	....	82·300	$\lambda=82{\cdot}300-0{\cdot}26758t+0{\cdot}0005717t^2$
Copper-silver (hard drawn)†	77·64 of Cu	....	69·311	$\lambda=69{\cdot}811-0{\cdot}21194t+0{\cdot}0004240t^2$
Copper-silver (hard drawn)†	46·67 of Cu	....	74·940	$\lambda=74{\cdot}940-0{\cdot}21011t+0{\cdot}0003961t^2$
Copper-silver (hard drawn)†	8·25 of Cu	....	80·284	$\lambda=80{\cdot}284-0{\cdot}22101t+0{\cdot}0003503t^2$
Copper-silver (hard drawn)†	1·53 of Cu	....	97·708	$\lambda=97{\cdot}708-0{\cdot}32868t+0{\cdot}0006965t^2$
Iron-gold (hard drawn)	27·93 of Fe	....	2·7350	$\lambda=2{\cdot}7350-0{\cdot}0095555t+0{\cdot}00001919t^2$
Iron-gold (hard drawn)	21·18 of Fe	....	1·9901	$\lambda=1{\cdot}9901-0{\cdot}0059194t+0{\cdot}00002426t^2$
Iron-gold (hard drawn)	10·96 of Fe	....	2·3102	$\lambda=2{\cdot}3102-0{\cdot}0011260t+0{\cdot}0000002391t^2$
Iron-copper (hard drawn)	0·46 of Fe	....	38·852	$\lambda=38{\cdot}852-0{\cdot}060341t+0{\cdot}00008128t^2$

TABLE X.

Alloy.	Weight per cent.	Conducting-power. A.	Conducting-power. B.	Formulæ for the correction of the conducting-power for temperature.
Phosphorus-copper (hard drawn)..	2·5 of P	7·301	7·343	$\lambda=7{\cdot}322-0{\cdot}0034870t+0{\cdot}000001052t^2$
Phosphorus-copper (hard drawn)..	0·95 of P	23·920	23·368	$\lambda=23{\cdot}644-0{\cdot}031238t+0{\cdot}00003882t^2$
Arsenic-copper (hard drawn)	5·4 of As	6·219	6·374	$\lambda=6{\cdot}296-0{\cdot}0023492t+0{\cdot}0000006230t^2$
Arsenic-copper (hard drawn)	2·8 of As	13·356	12·379	$\lambda=12{\cdot}867-0{\cdot}0094757t+0{\cdot}000005743t^2$
Arsenic-copper (hard drawn)	traces of As	60·854	61·255	$\lambda=61{\cdot}055-0{\cdot}16134t+0{\cdot}0002948t^2$

The values in columns A. and B. do not agree in all cases as well as might have been expected. Part of these differences are undoubtedly due to the fact that, the length of all wires made of alloys melting at a low temperature was measured after the determination had been made, as we found very great difficulty in soldering them to the thick copper wires in the trough, for, owing to their low fusing-points, the ends of the wires melted in with the solder. Now they had to be wound round a glass rod, as their length would not permit of their being experimented with in the trough without it; it is therefore probable that, on account of their softness, in unwinding and straightening them they became somewhat lengthened, which will account in a great measure for the differences. The value given for the conducting-power of one alloy (lead-silver, containing 30·64 per cent. of lead, and corresponding to $Pb\,Ag_2$) in the paper already referred to is wrong.

* These values have been altered to the same extent as those given in column B. for the hard-drawn wires, in order that the effect of annealing may remain the same.

† The alloys of these metals formerly tested do not quite correspond in composition to those here given, and therefore the values then found for their conducting-powers are not quoted above. They agree, however, very closely with those in column B.

We not only used part of the same alloy employed for the former determinations, but also made and analysed a fresh quantity, and found the values for the conducting-power in both cases the same; the present value is therefore the correct one for the conducting-power of the alloy. The error made in the former determinations must have been that a wrong normal wire was noted down as the one with which the resistances of the wires were compared; for according to the data from which the conducting-powers were then deduced, those there given are correct.

In order to show in a clear manner the results obtained, and to explain the law which we have arrived at, we will give in the first place the following Tables:—

Table XI.

Alloy.	Volumes per cent.	Conducting-power at 100°.		Percentage decrement.	
		Observed.	Calculated.	Observed.	Calculated.
Sn_6 Pb	83·96 of Sn	8·38	8·28	30·18	29·67
Sn_4 Cd	83·10 of Sn	10·35	10·10	28·89	30·03
Sn_2 Zn	77·71 of Sn	11·70	11·37	30·12	30·16
Pb Sn	53·41 of Pb	7·16	7·21	29·41	29·10
Zn Cd_2	26·06 of Zn	17·97	17·75	29·86	29·67
Sn Cd_4	23·50 of Sn	15·36	14·88	29·08	30·25
Cd Pb_6	10·57 of Cd	6·62	7·03	27·74	27·60

Table XII.

Alloy.	Volumes per cent.	Conducting-power at 100°.		Percentage decrement.	
		Observed.	Calculated.	Observed.	Calculated.
Lead-silver	94·64 of Pb	6·37	9·35	28·24	19·96
Lead-silver	46·90 of Pb	10·63	40·30	16·53	7·73
Lead-silver	30·64 of Pb	18·08	50·83	17·36	10·42
Tin-gold	90·32 of Sn	6·25	13·23	24·20	13·84
Tin-gold	79·54 of Sn	3·70	18·23	22·90	5·95
Tin-copper (hard drawn)	93·57 of Sn	8·58	12·72	28·71	19·76
Tin-copper (hard drawn)	83·60 of Sn	9·39	18·90	26·24	14·57
Tin-copper (hard drawn)	14·91 of Sn	8·37	61·42	5·18	3·99
Tin-copper (hard drawn)	12·35 of Sn	9·60	63·02	5·48	4·46
Tin-copper (hard drawn)	11·61 of Sn	11·30	63·47	6·60	5·22
Tin-copper (hard drawn)	6·02 of Sn	17·89	66·93	9·25	7·83
Tin-copper (hard drawn)	1·41 of Sn	48·89	69·78	21·74	20·53
Tin-silver	96·52 of Sn	8·67	10·90	30·00	23·31
Tin-silver	75·51 of Sn	9·71	23·91	29·18	11·89
Zinc-copper (hard drawn)	42·06 of Zn	19·09	49·57	12·40	11·29
Zinc-copper (hard drawn)	29·45 of Zn	19·21	55·89	11·49	10·08
Zinc-copper (hard drawn)	23·61 of Zn	24·68	58·82	12·79	12·30
Zinc-copper (hard drawn)	10·88 of Zn	38·76	65·20	17·41	17·42
Zinc-copper (hard drawn)	5·03 of Zn	47·93	68·13	20·61	20·62

TABLE XIII.

Alloy.	Volumes per cent.	Conducting-power at 100°.		Percentage decrement.	
		Observed.	Calculated.	Observed.	Calculated.
Gold-copper (hard drawn)	98·63 of Au	43·85	55·33	21·87	22·22
Gold-copper (hard drawn)	81·66 of Au	14·89	57·96	7·41	2·53
Gold-silver (hard drawn)	79·86 of Au	19·18	58·25	10·09	9·65
Gold-silver (annealed)	79·86 of Au	19·38	*a* 58·25 *b* 60·24	10·21	*a* 9·75 *b* 9·43
Gold-silver (hard drawn)	52·08 of Au	14·05	62·58	6·49	6·58
Gold-silver (annealed)	52·08 of Au	14·07	*a* 62·58 *b* 65·99	6·71	*a* 6·59 *b* 6·25
Gold-silver (hard drawn)	19·86 of Au	19·88	67·60	8·32	8·62
Gold-silver (annealed)	19·86 of Au	19·91	*a* 67·60 *b* 72·68	8·44	*a* 8·63 *b* 8·03
Gold-copper (hard drawn)	19·17 of Au	18·86	67·68	8·07	8·18
Gold-copper (hard drawn)	0·71 of Au	62·25	70·54	25·90	25·86
Platinum-silver (hard drawn)	19·65 of Pt	6·49	59·31	3·10	3·21
Platinum-silver (hard drawn)	5·05 of Pt	16·75	67·77	7·08	7·25
Platinum-silver (hard drawn)	2·51 of Pt	28·07	69·24	11·29	11·88
Platinum-silver (hard drawn)	23·28 of Pd	8·23	57·27	3·40	4·21
Copper-silver (hard drawn)	98·35 of Cu	65·81	70·66	26·50	27·30
Copper-silver (hard drawn)	95·17 of Cu	61·26	70·66	25·57	25·41
Copper-silver (hard drawn)	77·64 of Cu	52·86	70·66	24·29	21·92
Copper-silver (hard drawn)	46·67 of Cu	57·89	70·68	22·75	24·00
Copper-silver (hard drawn)	8·25 of Cu	61·69	70·69	23·17	25·57
Copper-silver (hard drawn)	1·53 of Cu	71·81	70·69	26·51	29·77
Iron-gold (hard drawn)	27·93 of Fe	1·97	42·62	27·92	1·47
Iron-gold (hard drawn)	21·18 of Fe	1·64	45·64	17·55	1·12
Iron-gold (hard drawn)	10·96 of Fe	2·20	49·68	3·84	1·34
Iron-copper (hard drawn)	0·46 of Fe	33·63	70·34	13·44	14·03

These Tables will require some explanation. Calculated conducting-power means the deduced conducting-power of an alloy, it being assumed that the conducting-power of a wire of any alloy is equal to the sum of the conducting-powers of parallel wires of the metals composing the alloy.

Under the term "calculated percentage decrement between 0° and 100°," we do not mean, as might be supposed, the mean of the percentage decrements which the component metals would suffer in their conducting-powers between 0° and 100°, and which would be, for nearly all the alloys experimented with, 29·307 per cent., inasmuch as it has been shown* that the conducting-power of most of the pure metals decreases between 0° and 100° by 29·307 per cent. (the exceptions to this law, being thallium and iron, the conducting-powers of which decrease between 0° and 100° 31·420 and 38·260 per cent. respectively†). It is therefore clear that the calculated percentage decrement in the conducting-powers between 0° and 100° of most alloys, from the above assumption, must be also 29·307 per cent. It is, however, obvious, on looking at the observed percentage decrements, that the conducting-powers of the alloys, with the exception of those given in Table XI., decrease less than 29·307 per cent. between 0° and 100°. In order to avoid repetitions, instead of the above value (29·307), we have inserted under the heading "calculated percentage decrement" that deduced from the following law:—

The observed percentage decrement in the conducting-power of an alloy between 0° *and* 100° *is to that calculated between* 0° *and* 100° (*viz.* 29·307) *as the observed conducting-power at* 100° *is to that calculated at* 100°.

* *Loc. cit.*

† Philosophical Transactions for 1863.

Or writing the above in symbols,

$$\text{Po} : \text{Pc} :: \lambda_{100^\circ} : \lambda'_{100^\circ}, \quad \ldots \ldots \ldots \quad (1)$$

where Po and Pc represent the observed and calculated percentage decrements in the conducting-power of the alloy between 0° and 100°, and λ_{100° and λ'_{100° its observed and calculated conducting-power at 100°, Pc is, as just stated, equal to 29·307 in nearly all cases, the exceptions being with the thallium and iron alloys.

If the values so deduced be examined, it will be seen that those given in Table XI. for the observed and calculated percentage decrement agree very closely with each other as well as with the mean value found for the percentage decrement in the conducting-power between 0° and 100° of the pure metals, viz. 29·307. This is just what we expected; for these alloys conduct electricity, as will be seen from the Table, in the ratio of their relative volumes, and therefore their conducting-powers ought to decrease between 0° and 100° in the same percentage amount as that of the mean of their components.

On looking at Table XII., which contains the alloys made of the metals belonging to the two classes, we find that, as long as there is no change in the conducting-power of the metals lead and tin by the addition of another metal, the conducting-power of the alloy decreases between 0° and 100° 29·307 per cent., but the moment the alloys show a greater or smaller conducting-power than that of pure lead or tin, then the percentage decrement is less than 29·307. Again, the alloys of tin or zinc with copper containing small amounts of those metals follow approximatively the above law; and on referring to the curves* which represent the conducting-powers of these alloys, it would appear that, starting with the metal whose conducting-power is greatly altered by a small addition of a foreign metal, the above law, as just stated, is approximatively true for all alloys as far as the turning-point of the curve, and from this point there is no agreement between the observed and calculated values. The difference between these values begins to show itself in some cases much sooner than in others; thus, with tin and copper after the addition of one per cent. of the former; with zinc and copper only after more than ten per cent. of zinc has been added, and from these points it gradually increases with each addition of metal. What the exact law is which these alloys follow with regard to the property under consideration we are unable at present to state, but some of them at least show that the law we have put forth will hold good in their cases. Unfortunately the alloys of this class, containing large percentages of each metal, are exceedingly brittle and unworkable, so that no complete series of determinations with any set of alloys could be made; had we been able to do this with one or two series, we should, in all probability, have found the law which regulates the influence of temperature on the conducting-power of this group of alloys. With regard to those in Table XIII. very little need be said, for the deduced percentage decrements prove that our law holds good for most of the alloys of this group. There are nevertheless a few remarks to be

* *Loc. cit.*

made respecting some of the values given in this Table, namely, on those of the annealed wires. Elsewhere it has been shown that the conducting-power of hard-drawn wires of some metals is greatly altered by annealing them; with the alloys this does not seem to be the case, for the differences here are very small. On account of their smallness we have not thought it worth while to investigate this matter any further at present; for to arrive at such results as might show the connexion between the effect of annealing on the conducting-power of alloys and on that of the metals composing them, would require a long series of experiments. Although the percentage decrements in the conducting-power of these annealed wires are all somewhat higher than those of the hard drawn, yet they may be considered the same, as the percentage decrements in the conducting-power of hard-drawn and annealed wires of the pure metals vary also in a small degree, but not always in the same direction. Thus those found for silver were—

Hard drawn.	Annealed.
28·67	28·82
28·44	28·67
27·82	28·21

We have calculated, as will be seen in the Table, the percentage decrements in two ways:—1st (*a*), using for the calculations the conducting-powers of the hard-drawn, and 2ndly (*b*), those of the annealed metals. The values so obtained for the percentage decrement do not differ very much from one another.

In calculating the results for the iron alloys, Pc has not been taken equal to 29·307, but for each alloy Pc has had to be calculated. Thus for the 1st, iron-gold, which contains 27·93 volumes per cent. iron,

The conducting-power of 1 volume of iron may be said to lose between 0° and 100° 38·260 per cent.; therefore 0·2793 volume will lose	10·686
That of 1 volume of gold may be said to lose between 0° and 100° 29·307 per cent.; therefore 0·7207 volume will lose	21·122
1 volume of iron-gold alloy, containing 27·93 per cent. iron, will therefore lose	31·808

On comparing the values obtained for the conducting-powers, &c. of the iron-gold alloys, the following facts are worth mentioning,—their very low and almost identical conducting-powers, and the high percentage decrements found for the first two and the low one for the third. That there was no error in this value we convinced ourselves by remaking the alloy, which contained, according to analysis, the same percentage amount of iron as that given in the Table, and the percentage decrement in its conducting-power was found equal to 4·04. Again, an alloy, made by a well-known firm*, which gave on analysis 11·94 volumes per cent. iron, conducted at 0° 2·097, and lost between 0° and 100° 4·30 per cent. of conducting-power. Unfortunately experiments with alloys richer

* We are indebted to Messrs. Johnson, Matthey and Co., of Hatton Garden, for many of the alloys experimented with. These were the first two, iron-gold, the platinum-silver, palladium-silver, and aluminium-nickel.

in iron could not be made, owing to the brittleness of the alloys; the high percentage decrement in the conducting-power of the first two indicating something abnormal, which it would have been interesting to have followed out.

On account of the probability of the arsenic and phosphorus being chemically combined with the copper, we have not considered it worth while to calculate the percentage decrements, and therefore no Table corresponding to the last has been made for these alloys.

If the above proportion,

$$\mathrm{Po} : \mathrm{Pc} :: \lambda_{100^\circ} : \lambda'_{100^\circ}, \quad \ldots \ldots \ldots \quad (1)$$

be converted into terms of resistance, the following formula is obtained,

$$r_{100^\circ} - r_{0^\circ} = r'_{100^\circ} - r'_{0^\circ}, \quad \ldots \ldots \ldots \quad (2)$$

where r_{100°, r_{0°, and r'_{100°, r'_{0° represent the observed and calculated resistances at 100° and 0°; for

$$\frac{\mathrm{Po}}{\mathrm{Pc}} = \frac{\lambda_{100^\circ}}{\lambda'_{100^\circ}};$$

but

$$\mathrm{Po} = 100 - \frac{\lambda_{100^\circ}}{\lambda_{0^\circ}} \cdot 100 = \frac{100}{\lambda_{0^\circ}}(\lambda_{0^\circ} - \lambda_{100^\circ}),$$

and

$$\mathrm{Pc} = 100 - \frac{\lambda'_{100^\circ}}{\lambda'_{0^\circ}} \cdot 100 = \frac{100}{\lambda'_{0^\circ}}(\lambda'_{0^\circ} - \lambda'_{100^\circ}).$$

And substituting these values in the above, we have

$$\frac{\lambda'_{0^\circ}}{\lambda_{0^\circ}} \cdot \frac{\lambda_{0^\circ} - \lambda_{100^\circ}}{\lambda'_{0^\circ} - \lambda'_{100^\circ}} = \frac{\lambda_{100^\circ}}{\lambda'_{100^\circ}},$$

or

$$\frac{\lambda_{0^\circ} - \lambda_{100^\circ}}{\lambda_{0^\circ} \cdot \lambda_{100^\circ}} = \frac{\lambda'_{0^\circ} - \lambda'_{100^\circ}}{\lambda'_{0^\circ} \cdot \lambda'_{100^\circ}},$$

or

$$\frac{1}{\lambda_{100^\circ}} - \frac{1}{\lambda_{0^\circ}} = \frac{1}{\lambda'_{100^\circ}} - \frac{1}{\lambda'_{0^\circ}},$$

which is equal to

$$r_{100^\circ} - r_{0^\circ} = r'_{100^\circ} - r'_{0^\circ}, \quad \ldots \ldots \ldots \quad (2)$$

for the reciprocal values of the conducting-powers of bodies are their resistances. The formula (2) expresses the fact that *the absolute difference between* 0° C. *and* 100° C. *in the resistance of an alloy is equal to the absolute difference between* 0° C. *and* 100° C. *in the calculated resistance of the alloy.*

The formula (2) may be written

$$r_{100^\circ} - r'_{100^\circ} = r_{0^\circ} - r'_{0^\circ}, \quad \ldots \ldots \ldots \quad (3)$$

which is equal to saying that *the absolute difference in the observed and calculated resistances at* 100° C. *is equal to the absolute difference between the observed and calculated resistances at* 0° C. Tables XIV., XV., and XVI. contain examples of these deductions taken from the three groups of alloys, taking the resistance of silver at 0° equal to 100.

Table XIV.

Alloy.	Volumes per cent.	$r_{100°}$.	$r_{0°}$.	$r'_{100°}$.	$r'_{0°}$.	$r_{100°}-r_{0°}$.	$r'_{100°}-r'_{0°}$.	$r_{100°}-r'_{100°}$.	$r_{0°}-r'_{0°}$.
Sn_8 Pb	83·96 of Sn	1193·3	833·3	1207·7	853·2	360·0	354·5	19·9	14·4
Sn_4 Cd	83·10 of Sn	966·2	686·8	990·1	699·8	279·4	290·3	23·9	13·0
Sn_2 Zn	77·71 of Sn	854·7	597·0	879·5	621·9	257·7	257·6	24·8	24·9
Pb Sn	53·41 of Pb	1396·6	986·2	1387·0	980·4	410·4	406·6	9·6	5·8
Zn Cd_2	26·06 of Zn	556·5	390·3	563·4	398·4	166·2	165·0	6·9	8·1
Sn Cd_4	23·50 of Sn	651·0	461·7	672·0	474·8	189·3	197·2	21·0	13·1
Cd Pb_6	10·57 of Cd	1510·6	1092·9	1422·2	1005·0	417·7	417·4	88·4	87·9

Table XV.

Alloy.	Volumes per cent.	$r_{100°}$.	$r_{0°}$.	$r'_{100°}$.	$r'_{0°}$.	$r_{100°}-r_{0°}$.	$r'_{100°}-r'_{0°}$.	$r_{100°}-r'_{100°}$.	$r_{0°}-r'_{0°}$.
Lead-silver	94·64 of Pb	1569·9	1126·1	1069·5	755·9	443·8	313·6	500·4	370·2
Lead-silver	46·90 of Pb	940·7	785·5	248·1	175·4	155·2	72·7	692·6	610·1
Lead-silver	30·64 of Pb	553·1	457·2	196·7	139·1	95·9	57·6	356·4	318·1
Tin-copper..................	93·57 of Sn	1165·5	831·3	786·2	555·6	334·2	230·6	379·3	275·7
Tin-copper..................	83·60 of Sn	1065·0	783·7	529·1	374·1	281·3	155·0	535·9	409·6
Tin-copper..................	14·91 of Sn	1196·2	1133·8	162·8	115·1	62·4	47·7	1033·4	1018·7
Tin-copper..................	12·35 of Sn	1041·6	985·2	158·7	112·2	56·4	46·5	882·9	873·0
Tin-copper..................	11·61 of Sn	885·0	826·4	157·6	111·4	58·6	46·2	727·4	715·0
Tin-copper..................	6·02 of Sn	559·0	507·1	149·4	105·6	51·9	43·8	409·6	401·5
Tin-copper..................	1·41 of Sn	204·5	160·1	143·3	101·3	44·4	42·0	61·2	58·8
Zinc-copper	42·06 of Zn	523·8	458·9	201·7	124·6	64·9	59·1	322·1	316·3
Zinc-copper	29·45 of Zn	520·6	460·6	178·9	126·5	60·0	52·4	341·7	334·1
Zinc-copper	23·61 of Zn	405·2	353·4	170·0	120·2	51·8	49·8	235·2	233·2
Zinc-copper	10·88 of Zn	258·0	215·1	153·4	108·4	44·9	45·0	104·6	104·7
Zinc-copper	5·03 of Zn	208·6	165·6	146·8	103·8	43·0	43·0	61·8	61·8

Table XVI.

Alloy.	Volumes per cent.	$r_{100°}$.	$r_{0°}$.	$r'_{100°}$.	$r'_{0°}$.	$r_{100°}-r_{0°}$.	$r'_{100°}-r'_{0°}$.	$r_{100°}-r'_{100°}$.	$r_{0°}-r'_{0°}$.
Gold-copper (hard drawn) ...	98·63 of Au	228·1	198·2	180·7	127·8	49·9	52·9	47·4	50·4
Gold-copper (hard drawn) ...	81·66 of Au	671·5	621·9	172·5	122·0	49·6	50·5	499·0	499·9
Gold-silver (hard drawn) ...	79·86 of Au	521·4	468·8	171·7	121·4	52·6	50·3	349·7	347·4
Gold-silver (hard drawn) ...	52·08 of Au	711·7	665·3	159·8	113·0	46·4	46·8	551·9	552·3
Gold-silver (hard drawn) ...	19·86 of Au	503·0	461·2	147·9	104·6	41·8	43·3	355·1	356·6
Gold-copper (hard drawn) ...	19·17 of Au	530·2	487·6	147·8	104·5	42·6	43·3	382·4	383·1
Gold-copper (hard drawn) ...	0·71 of Au	160·6	119·0	141·8	100·2	41·6	41·6	18·8	18·8
Platinum-silver (hard drawn)	19·65 of Pt	1540·8	1492·5	168·6	119·2	48·3	49·4	1372·2	1373·3
Platinum-silver (hard drawn)	5·05 of Pt	597·0	554·6	147·6	104·3	42·4	43·3	449·4	450·3
Platinum-silver (hard drawn)	2·51 of Pt	356·3	316·1	144·4	102·1	40·2	42·3	211·9	214·0

What has already been said when speaking of the results contained in Tables XI., XII., and XIII., will of course apply here. In Table XIV., the values in the columns headed $r_{100°}-r'_{100°}$ and $r_{0°}-r'_{0°}$ do not agree in all cases; and at the first glance we should be inclined to suppose that the law was not as correct for these alloys as for those given in Table XVI.; but this is only due to slight errors in the determination of the resistances, &c., for a small percentage difference in these numbers will cause a very marked one in those under the headings $r_{100°}-r'_{100°}$ and $r_{0°}-r'_{0°}$. If, on the contrary, the values in the columns $r_{100°}-r_{0°}$ and $r'_{100°}-r'_{0°}$ in Tables XIV. and XVI. be compared with each other, it will be seen that those in Table XIV. agree together quite as well as those in

Table XVI.; and therefore, if the values in Table XIV. were smaller, those in the columns headed $r_{100°}-r'_{100°}$ and $r_{0°}-r'_{0°}$ would agree much better together.

If

$$r_{100°}-r'_{100°}=r_{0°}-r'_{0°} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

be correct, we may suppose that

$$r_t-r'_t=r_{0°}-r'_{0°};$$

that is, *the absolute difference between the observed and calculated resistances of an alloy at any temperature is equal to the absolute difference between the observed and calculated resistances at* 0° C.; or, in other words,

$$r_t-r'_t=\text{constant.} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Table XVII. contains some examples which show this to be the case.

TABLE XVII.

Alloy.	T.	r.	r'.	Difference.
Cd Pb_6	0°	1092·9	1005·0	87·9
	20	1171·0	1083·0	88·0
	40	1253·1	1164·9	88·2
	60	1338·7	1249·8	88·9
	80	1424·5	1335·8	88·7
	100	1510·6	1422·2	88·4
Gold-copper, containing 0·71 volume per cent. of gold	0	119·04	100·21	18·83
	20	127·11	107·98	19·13
	40	135·44	116·16	19·28
	60	143·92	124·63	19·29
	80	152·39	133·21	19·18
	100	160·64	141·76	18·88
Gold-silver, containing 79·86 volumes per cent. of gold	0	468·71	121·36	349·35
	20	479·00	130·77	348·23
	40	489·38	140·67	348·71
	60	499·93	150·92	349·01
	80	510·57	161·31	349·26
	100	521·30	171·67	349·63

The values given in the column r were calculated with the help of the formulæ from Tables VII. and IX., those in the column r' with that deduced for the correction of conducting-power for temperature of most of the pure metals, namely,

$$\lambda=100-0·37647t+0·0008340t^2.$$

If, now,

$$r_t-r'_t=\text{constant,} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

it is clear that we may deduce the formula for the correction of resistance or conducting-power for temperature of an alloy as soon as we know its composition and its resistance at any temperature; for, as $r'_{100°}$, $r'_{0°}$, and r'_t may be calculated by means of the formula given for the correction of conducting-power for temperature for most of the pure metals, viz.

$$\lambda=100-0·37647t+0·0008340t^2*,$$

* *Loc. cit.*

if the constant $r_t - r'_t$ be determined, then

$$\begin{aligned} r_{100^\circ} &= r'_{100^\circ} + \text{constant}, \\ r_t &= r'_t + \text{constant}, \\ r_{0^\circ} &= r'_{0^\circ} + \text{constant}; \end{aligned}$$

and from these terms a formula for the correction of resistance or conducting-power for temperature may be calculated, which in most cases will be found very near the truth. Thus, take, for instance, the gold-silver alloy containing 79·86 volumes per cent. gold (hard drawn), and we find

the first observed conducting-power . . . 21·010 at 11°·7,
that calculated . . . . 78·866 at 11°·7,
hence the resistance observed is . . . . 475·96 at 11°·7,
that calculated . . . . 126·80 at 11°·7;
therefore $r_t - r'_t = 349{\cdot}16$.
But the calculated resistance at . . . . . 0°=121·36,
" " " . . . . . 50°=145·75,
" " " . . . . . 100°=171·67,
therefore r, the true resistance, will be at . . 0°=121·36+349·16=470·52,
" " " " . . 50°=145·75+349·16=494·91,
" " " " . . 100°=171·67+349·16=521·83;
or the conducting-powers will be at . . . . 0°=21·253,
" " " " . . 50°=20·206,
" " " " . . 100°=19·200.

The formula deduced from these numbers is

$$\lambda = 21{\cdot}253 - 0{\cdot}021350t + 0{\cdot}000008200t^2.$$

The conducting-power, according to this formula, of the alloy at 11°·45 will be 21·010; but after having kept the alloys at 100° for three days it altered, and was found at that temperature to conduct 21·031. If the above formula be multiplied by $\frac{21{\cdot}031}{21{\cdot}010} = 1{\cdot}001$, we arrive at

$$\lambda = 21{\cdot}274 - 0{\cdot}021372t + 0{\cdot}000008208t^2;$$

and if the conducting-powers be calculated for the different temperatures in the following series, the difference between the observed and calculated values will be found to be very small.

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
11°·45	21·031	21·031	0·000
26·04	20·698	20·723	−0·025
40·04	20·391	20·421	−0·030
55·26	20·065	20·118	−0·053
67·73	19·806	19·864	−0·058
84·13	19·463	19·534	−0·071
98·45	19·175	19·250	−0·075

Another example: the gold-copper alloy containing 0·71 volume per cent. gold (hard drawn) conducts 79·884 at 15°·3; the formula deduced in exactly the same manner as the above was

$$\lambda=83·843-0·26810t+0·0005152t^2;$$

and the formula deduced from this, with the help of which the following calculated values were obtained, was

$$\lambda=84·204-0·26926t+0·0005174t^2.$$

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
17·27°	79·709	79·708	0·000
28·98	77·952	78·045	−0·093
39·55	74·154	74·364	−0·210
54·26	70·924	71·118	−0·194
69·26	67·920	68·037	−0·117
83·86	65·213	65·263	−0·050
98·78	62·645	62·656	−0·011

Again, let us take another example, the alloy Sn_4 Cd, for which the values (Table XIV.) obtained for $r_{100°}-r'_{100°}$ and $r_{0°}-r'_{0°}$ agree worse than any other in that Table; and if the results agree, it will show that the differences in these values are, as before stated, due to errors of observation.

The first observed conducting-power was 14·259 at 6°·8.

The formula deduced, as above, was

$$\lambda=14·641-0·055250t+0·0001158t^2.$$

That deduced to calculate the conducting-powers for comparison with those observed, was

$$\lambda=14·455-0·054673t+0·0001141t^2.$$

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
8·72°	13·986	13·968	0·000
25·52	13·086	13·134	−0·045
39·50	12·419	12·473	−0·054
54·96	11·770	11·795	−0·025
69·40	11·218	10·211	+0·007
84·02	10·933	10·666	+0·067
98·85	10·333	10·166	+0·167

These examples are sufficient to prove that the law we have put forth is correct for most of the two metal alloys; we might have experimented with many more alloys whose conducting-power would have followed the above law, but we thought determinations with a few members of each group of alloys would suffice to prove its correctness for most of them. We have endeavoured rather to find the exemptions to the law than to obtain a large number of results which will agree with it.

II. *Experiments on the Influence of Temperature on the Electric Conducting-power of some Alloys composed of three Metals.*

In the course of the foregoing experiments we were induced to try whether the influence of temperature on the conducting-power of the three metal alloys would be regulated by the above law, and Tables XVIII. and XIX. contain the results.

Table XVIII.

1.

Gold-copper-silver alloy, containing 50 volumes per cent. gold, 25 copper, and 25 silver (hard drawn).

Length 341·5 millims.; diameter 0·618 millim.

		Reduced to 0°.
Conducting-power found before heating the wire......	10·6186 at 13°·7	10·6960
Ditto, after being kept at 100° for 1 day	10·6367 at 6·0	10·6681
Ditto, for 2 days	10·5855 at 6·7	10·6232

T.	Conducting-power. Observed.	Conducting-power. Calculated.	Difference.
10°·75	10·5637	10·5617	+0·0020
33·52	10·4341	10·4346	−0·0005
55·15	10·3130	10·3148	−0·0018
78·35	10·1846	10·1873	−0·0027
97·52	10·0857	10·0828	+0·0029

$$\lambda = 10{\cdot}6220 - 0{\cdot}0056248t + 0{\cdot}0000009863t^2.$$

2.

Gold-copper-silver alloy, containing 40·67 vols. per cent. gold, 39·81 copper, and 19·52 silver (hard drawn).

Length 532 millims.; diameter 0·625 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	12·007 at 15°·1	12·109
Ditto, after being kept at 100° for 1 day	11·978 at 15·5	12·083
Ditto, for 2 days..................	11·915 at 16·5	12·026
Ditto, for 3 days..................	11·914 at 15·9	12·020

T.	Conducting-power.
9°·0	11·956
54·5	11·647
100·0	11·438

$$\lambda = 12{\cdot}017 - 0{\cdot}0069033t + 0{\cdot}00001111t^2.$$

3.

Gold-copper-silver alloy, containing 3·67 vols. per cent. gold, 83·32 copper, and 13·01 silver (hard drawn).

Length 764 millims.; diameter 0·553 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	44·820 at 18°·4	44·272
Ditto, after being kept at 100° for 1 day	42·994 at 17·1	44·348
Ditto, for 2 days..................	42·983 at 18·2	44·424
Ditto, for 3 days..................	43·047 at 17·0	44·395

T.	Conducting-power.
11°·0	43·591
55·5	40·300
100·0	37·560

$$\lambda = 44{\cdot}472 - 0{\cdot}081525t + 0{\cdot}0001240t^2.$$

Table XIX.

Alloy.	Volumes per cent.	Conducting-power at 100°. Observed.	Conducting-power at 100°. Calculated.	Percentage decrement. Observed.	Percentage decrement. Calculated.
Gold-copper-silver (hard drawn).	50 Au 25 Cu 25 Ag	10·14	62·89	5·20	4·72
Ditto	40·67 Au 39·81 Cu 19·52 Ag	11·52	64·34	4·82	5·25
Ditto	3·67 Au 83·32 Cu 13·01 Ag	37·39	70·09	15·54	15·63
Argentan	12·84 Ni* 36·57 Zn 50·59 Cu	7·46	44·44	4·39	4·93

* Values found by analysis. Of this wire all our normal wires were made. According to former experiments (Philosophical Transactions, 1862, p. 5), the formula for the correction of conducting-power for temperature of this alloy was

$$\lambda = 7{\cdot}803 - 0{\cdot}0034619t + 0{\cdot}0000003951t^2.$$

The values in Table XIX. indicate that the law will probably hold good for most of the three metal alloys.

There is, however, one of the three metal alloys which we cannot pass over unnoticed, namely, that of copper-nickel-zinc or argentan (german silver). This alloy has long been used, on account of the small effect which temperature has on its conducting-power, for making resistance coils, &c. It is a somewhat curious fact, that the conducting-power of this commercial alloy decreases less between 0° and 100° than almost any other alloy yet known, for in the course of this investigation we have only found the following which show a smaller percentage decrement in their conducting-power than argentan.

The conducting-power of the platinum-silver alloy, containing 19·65 volumes per cent. platinum, decreases between 0° and 100° 3·10 per cent.

The conducting-power of the palladium-silver alloy, containing 23·38 volumes per cent. palladium, decreases between 0° and 100° 3·40 per cent.

The conducting-power of the iron-gold alloy, containing 10·96 volumes per cent. iron, decreases between 0° and 100° 3·84 per cent.

The conducting-power of the argentan decreases between 0° and 100° 4·39 per cent.

III. *On a Method by which the Conducting-power of a Pure Metal may be deduced from that of the Impure one.*

This part of our subject is an important deduction from the law

$$\mathrm{Po} : \mathrm{Pc} :: \lambda_{100°} : \lambda'_{100°}; \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

for if we consider the two last terms of the proportion, and bear in mind that a small amount of another metal has very little or no effect on $\lambda'_{100°}$, when it represents the conducting-power of an alloy containing a very small percentage of the one metal, whereas it has a very considerable one on $\lambda_{100°}$, we may write the proportion

$$\mathrm{P} : \mathrm{P}' :: \mathrm{M}_{100°} : \mathrm{M}'_{100°}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

where P and P′ represent the observed and calculated percentage decrements in the conducting-power of the impure and pure metals between 0° and 100°, and $\mathrm{M}_{100°}$ and $\mathrm{M}'_{100°}$ their conducting-powers at 100°. P′ is for most metals 29·307, or we may express it as follows:—

The percentage decrement in the conducting-power of an impure metal between 0° C. *and* 100° C., *is to that of the pure one between* 0° C. *and* 100° C. *as the conducting-power of the impure metal at* 100° C. *is to that of the pure one at* 100° C.

From the results given in Tables XII. and XIII., we have chosen the following alloys to show that a small amount of foreign metal has no influence on the value $\lambda'_{100°}$, which may therefore be looked upon as equal to $\mathrm{M}'_{100°}$.

TABLE XX.

Alloy.	Volumes per cent.	Conducting-power at 100°.		
		Observed.	Calculated.	
Tin-copper (hard drawn)	1·41 of Sn	48·89	69·78	Pure copper conducts at 100° 70·27.
Zinc-copper (hard drawn)	5·03 of Zn	47·93	68·13	
Gold-copper (hard drawn)	1·37 of Cu	43·85	55·33	Pure gold conducts at 100° 55·90.
Gold-copper (hard drawn)	0·71 of Au	62·25	70·54	Pure copper conducts at 100° 70·27.
Platinum-silver (hard drawn) ...	2·51 of Pt	28·07	69·24	Pure silver conducts at 100° 71·53.
Copper-silver (hard drawn)	1·65 of Ag	65·81	70·66	Pure copper conducts at 100° 70·27.

If now, as in the case of most commercial metals, the amount of impurity be much smaller than that in the Table, then of course its influence on the value λ'_{100} is so small that it may be entirely disregarded.

In Tables XXI., XXII., and XXIII., we give some results obtained with impure metals, the conducting-power of the same metal in a pure state having been previously determined.

TABLE XXI.

1.

Gold, containing traces of silver (hard drawn).

Length 1564 millims.; diameter 0·525 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	69·612 at 10°·2	72·056
Ditto, after being kept at 100° for 1 day	70·069 at 10·4	72·578
Ditto, for 2 days.................	69·274 at 13·8	72·578

T.	Conducting-power.
15°·0	68·969
57·5	60·179
100·0	53·387

$$\lambda=72\cdot548-0\cdot24692t+0\cdot0005531t^2.$$

2.

Copper, containing traces of tin (hard drawn).

Length 2008 millims.; diameter 0·518 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	88·357 at 12°·8	92·503
Ditto, after being kept at 100° for 1 day	88·690 at 12·6	92·786
Ditto, for 2 days.................	89·589 at 10·1	92·894

T.	Conducting-power.
11°·0	89·319
55·5	76·619
100·0	66·863

$$\lambda=92\cdot912-0\cdot33482t+0\cdot0007433t^2.$$

TABLE XXI. (continued).

3.

Copper, containing traces of zinc (hard drawn).

Length 1992 millims.; diameter 0·577 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	81·306 at 18°·2	86·490
Ditto, after being kept at 100° for 1 day	83·185 at 12·8	86·896
Ditto, for 2 days.................	83·021 at 12·8	86·725

T.	Conducting-power.
13°·0	82·960
56·5	72·071
100·0	63·786

$$\lambda=86\cdot719-0\cdot29814t+0\cdot0006881t^2.$$

4.

Copper, commercial, containing traces of iron, nickel, lead, and suboxide of copper (hard drawn).

Length 2091 millims.; diameter 0·546 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	74·209 at 16°·6	78·023
Ditto, after being kept at 100° for 1 day	74·610 at 16·2	78·350
Ditto, for 2 days.................	74·563 at 16·8	78·441
Ditto, for 3 days.................	74·283 at 18·0	78·427

T.	Conducting-power.
12°·0	75·668
56·0	66·584
100·0	59·351

$$\lambda=78\cdot467-0\cdot23896t+0\cdot0004780t^2.$$

Table XXI. (continued).

5.

Copper, commercial, containing same impurities as No. 3 (hard drawn).

Length 2246 millims.; diameter 0·549 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	74·660 at 16°·8	78·705
Ditto, after being kept at 100° for 1 day	74·958 at 16·4	78·921
Ditto, for 2 days	74·946 at 16·6	78·958
Ditto, for 3 days	74·576 at 18·2	78·958

T.	Conducting-power.
13°·0	75·979
56·5	76·738
100·0	59·633

$$\lambda=79{\cdot}155-0{\cdot}25166t+0{\cdot}0005644t^2.$$

6.

Copper, commercial, containing traces of lead, iron, antimony, and suboxide of copper (hard drawn).

Length 3010 millims.; diameter 0·606 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	89·258 at 16°·7	94·896
Ditto, after being kept at 100° for 1 day	89·241 at 17·4	95·118
Ditto, for 2 days	89·524 at 16·5	95·109

T.	Conducting-power.
10°·0	91·849
55·0	78·402
100·0	68·324

$$\lambda=95{\cdot}294-0{\cdot}35289t+0{\cdot}0008309t^2.$$

7.

Silver, containing traces of lead (hard drawn).

Length 1473 millims.; diameter 0·513 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	64·909 at 13°·6	66·997
Ditto, after being kept at 100° for 1 day	65·957 at 14·6	68·235
Ditto, for 2 days	66·404 at 13·6	68·539
Ditto, for 3 days	66·801 at 11·4	68·599

T.	Conducting-power.
12°·0	66·543
56·0	60·264
100·0	54·987

$$\lambda=68{\cdot}429-0{\cdot}16030t+0{\cdot}0002588t^2.$$

Table XXI. (continued).

8.

Silver, containing traces of tin (hard drawn).

Length 2025 millims.; diameter 0·579 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	71·427 at 13°·6	73·964
Ditto, after being kept at 100° for 1 day	72·668 at 13·8	75·287
Ditto, for 2 days	72·735 at 13·7	75·338

T.	Conducting-power.
14°·0	72·696
57·0	65·305
100·0	59·085

$$\lambda=75{\cdot}355-0{\cdot}19437t+0{\cdot}0003167t^2.$$

9.

Silver, containing traces of gold (hard drawn).

Length 1780 millims.; diameter 0·648 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	70·847 at 10°·4	72·717
Ditto, after being kept at 100° for 1 day	71·205 at 11·3	73·249
Ditto, for 2 days	70·951 at 13·5	73·389
Ditto, for 3 days	70·929 at 13·5	73·366

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
14°·37	70·763	70·746	+0·017
24·21	69·036	69·044	−0·008
39·25	66·531	66·555	−0·024
54·43	64·172	64·179	−0·007
69·51	61·977	61·954	+0·023
84·30	59·923	59·905	+0·018
98·60	58·028	58·047	−0·019

$$\lambda=73{\cdot}336-0{\cdot}18447t+0{\cdot}0002982t^2.$$

10.

Silver, containing minute traces of arsenic (hard drawn).

Length 1298 millims.; diameter 0·376 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	85·119 at 14°·0	88·931
Ditto, after being kept at 100° for 1 day	86·795 at 9·0	89·285
Ditto, for 2 days	87·881 at 7·4	89·949
Ditto, for 3 days	87·091 at 10·0	89·869

T.	Conducting-power.
11°·0	87·029
55·5	76·185
100·0	67·767

$$\lambda=90{\cdot}084-0{\cdot}28442t+0{\cdot}0006125t^2.$$

TABLE XXII.

Metal.	Impurity.	Observed percentage decrement in the conducting-power between 0° and 100°.	Conducting-power.	
			Observed at 0°.	Calculated for the pure metal at 0°.
Lead	Bismuth	27·66*	7·86	8·53
Tin	Copper	28·71†	12·03	12·39
Tin	Silver	30·00†	12·39	11·98
Gold (hard drawn)	Copper	21·87‡	56·12	83·11
Gold (hard drawn)	Silver	26·41	72·06	83·24
Copper (hard drawn)	Tin	28·04	92·50	98·42
Copper (hard drawn)	Zinc	26·44	86·49	99·75
Copper (hard drawn)	Gold	25·90‡	84·01	99·64
Copper (hard drawn)	Silver	26·50‡	89·54	102·95
Copper (hard drawn)	Iron, nickel, lead, and suboxide of copper	24·36	78·02	100·43
Copper (hard drawn)	Ditto	24·66	78·70	99·67
Copper (hard drawn)	Lead, iron, antimony, and suboxide of copper	28·30	94·90	99·67
Silver (hard drawn)	Lead	19·64	67·00	113·64
Silver (hard drawn)	Tin	21·59	73·69	111·33
Silver (hard drawn)	Gold	21·09	72·72	112·79
Silver (hard drawn)	Copper	23·17‡	80·28	110·39
Silver (hard drawn)	Copper	26·51‡	97·71	112·28
Silver (hard drawn)	Minute traces of arsenic	24·77	88·93	111·95

On comparing the values in Table XXII. for the observed and calculated conducting-powers, it will be seen that those calculated for the same metal agree very closely with each other, whereas those observed vary in some cases more than 20 per cent. From Table XXIII. it is evident that the deduced value for the conducting-power of gold and silver is much higher than that found by experiment; on referring, however, to the paper on the influence of temperature on the conducting-power of metals (Table XVI.), it will be found that the percentage decrement in the conducting-power between 0° and 100° of

Silver is . . . . . 28·44
Copper is . . . . 29·69
Gold is . . . . . 21·30
Tin is . . . . . 29·89
Lead is . . . . . 29·61

Let us now recalculate the deduced conducting-powers, using these values instead of the mean of those found for the pure metals (viz. 29·307), and we arrive at much better results. These are shown in Table XXIII.

TABLE XXIII.

	Deduced from the impure metals.	Conducting-power at 0°.		Deduced from the impure metals, using the observed percentage decrements.
		Observed for hard-drawn wires.	Observed for annealed wires.	
Lead	8·53	8·32	——	8·65
Tin	12·19	12·36	——	12·54
Gold (hard drawn)	83·17	77·96	79·33	79·20
Copper (hard drawn)	100·06	99·95	102·21	101·91
Silver (hard drawn)	112·06	100·00	108·57	107·43

* From Table XXVII. † From Table XII. ‡ From Table XIII.

The values in the last column were obtained as follows: take for instance that of gold. The mean deduced value (column 1) for its conducting-power at 0° was 83·17, under the supposition that the percentage decrement in its conducting-power between 0° and 100° was 29·307; the percentage decrement, however, found for pure gold was 28·30; we must therefore recalculate the deduced value to obtain a more concordant one, and this may be done with the help of the proposition

$$P : P' :: M_{100°} : M'_{100°} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (5)$$

First,

$$M_{100°} = \frac{83·17 \times 70·693}{100} = 58·80,$$

then

$$29·307 : 28·30 :: 58·80 : M'_{100°};$$

ence

$$M'_{100°} = 56·77,$$

and therefore the deduced value at 0°

$$\frac{56·77 \times 100}{71·7} = 79·20.$$

Reducing the others in the same manner, we are struck with the coincidence of these values with those really found for the annealed wires by experiment; in fact we must assume that the values deduced for the conducting-power of metals are those of the annealed wires, even when hard-drawn ones are experimented with. What the deduced values for the conducting-power would be when using annealed wires of impure metals we are unable at present to say, for no determinations have been made in this direction. It must be remembered that the effect of annealing on the conducting-power of alloys is very small, so that the deduced values from those found for the annealed wires would not be very different from those deduced from the hard drawn, assuming, as we have done in the former part of this investigation, that the percentage decrement in the conducting-power between 0° and 100° of hard drawn and annealed is the same.

Having thus proved that, by using the expression

$$P : P' :: M_{100°} : M'_{100°}, \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (5)$$

we may deduce the conducting-power of the pure metal from the impure one, when the observed values do not differ from those calculated by more than 20 to 30 per cent., we will now proceed to give the results of some experiments with impure metals where the conducting-power of the same metals in a pure state has not yet been determined. Tables XXIV. and XXV. contain the results.

Table XXIV.

1.

Platinum, commercial (hard drawn).

Length 371 millims.; diameter 0·614 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	11·209 at 16°·6	11·720
Ditto, after being kept at 100° for 1 day	11·212 at 15·6	11·692
Ditto, for 2 days	11·174 at 16·7	11·687
Ditto, for 3 days	11·159 at 16·8	11·647

T.	Conducting-power.
9°·0	11·427
54·5	10·172
100·0	9·197

$$\lambda=11\cdot708-0\cdot031875t+0\cdot00006762t^2.$$

2.

Platinum, commercial (hard drawn).

Length 209 millims.; diameter 0·243 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	11·039 at 17°·0	11·527
Ditto, after being kept at 100° for 1 day	11·038 at 17·3	11·535
Ditto, for 2 days	11·022 at 17·6	11·527

T.	Conducting-power.
11°·0	11·239
55·0	10·072
100·0	9·141

$$\lambda=11\cdot530-0\cdot029721t+0\cdot00005827t^2.$$

3.

Palladium, commercial (hard drawn).

Length 167·5 millims.; diameter 0·379 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	13·230 at 18°·4	13·991
Ditto, after being kept at 100° for 1 day	13·295 at 17·5	14·022
Ditto, for 2 days	13·322 at 16·9	14·025

T.	Conducting-power.
9°·0	13·645
54·5	11·954
100·0	10·658

$$\lambda=14\cdot026-0\cdot043225t+0\cdot00009540t^2.$$

4.

Palladium, commercial (hard drawn).

Length 218 millims.; diameter 0·409 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	12·091 at 17°·2	12·678
Ditto, after being kept at 100° for 1 day	12·087 at 17·6	12·684

T.	Conducting-power.
10°·0	12·357
55·0	10·978
100·0	9·818

$$\lambda=12\cdot704-0\cdot035443t+0\cdot00007383t^2.$$

Table XXIV. (continued).

5.

Magnesium, commercial.

Length 717 millims.; diameter 0·497 millim.

T.	Conducting-power.
15°·0	34·912
57·5	30·312
100·0	26·922

$$\lambda=36\cdot825-0\cdot13252t+0\cdot0003349t^2.$$

6.

Magnesiun (from Mr. E. Sonstadt).

Length 628 millims.; diameter 0·436 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	38·062 at 11°·0	39·662
Ditto, after being kept at 100° for 1 day	37·963 at 12·2	39·735
Ditto, for 2 days	37·918 at 12·6	39·747

T.	Conducting-power.
13°·0	37·881
56·5	32·442
100·0	28·347

$$\lambda=39\cdot765-0\cdot14971t+0\cdot0003351t^2.$$

7.

Aluminium, commercial (hard drawn).

Length 1351 millims.; diameter 0·511 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	50·804 at 17°·2	54·073
Ditto, after being kept at 100° for 1 day	51·079 at 16·4	54·210
Ditto, for 2 days	51·146 at 15·7	54·145
Ditto, for 3 days	51·035 at 16·4	54·163

T.	Conducting-power.
12°·0	51·910
56·0	44·542
100·0	38·938

$$\lambda=54\cdot225-0\cdot19843t+0\cdot0004556t^2.$$

8.

Aluminium, alloyed with 0·5 per cent. nickel (hard drawn).

Length 745 millims.; diameter 0·415 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	44·597 at 15°·9	46·950
Ditto, after being kept at 100° for 1 day	44·786 at 15·2	47·043
Ditto, for 2 days	45·044 at 13·6	47·071

T.	Conducting-power.
14°·0	44·986
57·0	39·325
100·0	34·785

$$\lambda=47\cdot071-0\cdot15321t+0\cdot0003037t^2.$$

TABLE XXV.

Metal.	Observed percentage decrement in the conducting-power between 0° and 100°.	Conducting-power at 0°. Observed.	Conducting-power at 0°. Calculated for the pure metal.	Mean.
Platinum (1)...............	21·45	11·72	17·79	18·03
Platinum (2)...............	20·73	11·53	18·28	
Palladium (3)	24·01	13·99	18·35	18·44
Palladium (4)	22·09	12·68	18·54	
Magnesium (5)............	26·89	36·82	41·50	44·17
Magnesium (6)............	28·72	39·66	40·85	
Aluminium (7)............	28·19	54·07	57·01	56·06
Aluminium (8)............	26·10	46·95	55·12	

[It is scarcely necessary to add, that in the same manner as the formulæ for the correction of conducting-power for temperature may in most cases be deduced where the composition and conducting-power of an alloy at any temperature are known, that for the correction of the conducting-power for temperature of an impure metal may also be calculated, using the conducting-power of the annealed metal for λ'_0, λ'_t, λ'_{100}. This is of practical importance; for in testing copper wire for telegraphic purposes, the formula for the correction of its conducting-power for temperature may be easily deduced, of course only in cases where the conducting-power is within the limits above stated. It has already been elsewhere shown that the conducting-power of commercial metals, copper for instance, varies considerably according to the state of its purity. Thus a specimen of Rio Tinto copper was found to conduct as follows:—

Length 398 millims.; diameter 0·331 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	13·480 at 16°·6	13·622
Ditto, after heating to 100° for 1 day	13·473 at 16·9	13·586
Ditto, for 2 days..................	13·442 at 14·9	13·573
Ditto, for 3 days..................	13·420 at 15·7	13·558
Ditto, for 4 days..................	13·418 at 16·0	13·558

T.	Conducting-power.
14°·67	13·429
57·33	13·064
100·00	12·713

$$\lambda = 13{\cdot}558 - 0{\cdot}0088326t + 0{\cdot}000003844t^2$$

which corresponds to a percentage decrement of only 6·23, whereas the conducting-power of pure copper decreases between 0° and 100° C. 29·69 per cent.—Feb. 1864.]

Table XXVI. contains a list of the conducting-powers of metals in a pure state. Those marked with a † are those deduced from the impure metals, and they may be called *the probable values for the conducting-powers of annealed wires of the metals.*

TABLE XXVI.

Metal.	Conducting-power at 0°.		
	Hard drawn.	Pressed.	Annealed.
Silver	100·00	....	108·57
Copper	99·95	....	102·21
Gold	77·96	....	79·33
Aluminium	....	....	56·06†
Magnesium	....	....	41·17†
Zinc	....	29·02	
Cadmium	....	23·72	
Palladium	....	....	18·44†
Platinum	....	....	18·03†
Cobalt	....	....	17·22† *
Iron	....	....	16·81† *
Nickel	....	....	13·11† *
Tin	....	12·36	
Thallium	....	9·16	
Lead	....	8·23	
Arsenic	....	4·76	
Antimony	....	4·62	
Bismuth	....	1·245	
Gold-silver alloy	15·03		

IV. *Miscellaneous and general remarks.*

Having thus described the results obtained in this investigation, it only remains for us to make a few general remarks on them.

1. The percentage decrement in the conducting-power of alloys between 0° and 100° is never greater than that of the pure metals composing them; for on looking at Tables XI., XII., and XIII., we only find a few cases where the observed percentage decrement is greater than that of the pure metals composing the alloy, and in these the differences are so small that they are undoubtedly due to small errors in the observations, for the differences between the percentage decrements are not greater than those obtained for different wires of the same metal.

2. The conducting-power of alloys decreases with an increase of temperature. This, however, is not strictly true for all alloys, for we already know of some where this is not the case, viz. a few of the bismuth alloys. The results of our observations are given in the following Table:—

TABLE XXVII.

1.

†Bi Pb_{100}, containing 2·27 volumes per cent. bismuth.

Length 243 millims.; diameter 0·512 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	7·697 at 14°·5	8·090
Ditto, after being kept at 100° for 1 day	7·715 at 14·1	8·099

T.	Conducting-power.
15°·0	7·693
57·5	6·675
100·0	5·860

$$\lambda = 8{\cdot}101 - 0{\cdot}0280217t + 0{\cdot}00005619t^2.$$

		Reduced to 0°.
The conducting-power found in a former research ‡ was	7·03 at 24°·0	7·633

2.

†Bi Pb_{10}, containing 18·85 volumes per cent. bismuth.

Length 122·5 millims.; diameter 0·673 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	4·4167 at 15°·6	4·5799
Ditto, after being kept at 100° for 1 day	4·4479 at 10·6	4·5586
Ditto, for 2 days	4·4378 at 11·5	4·5577
Ditto, for 3 days	4·4285 at 12·5	4·5587

T.	Conducting-power.		Difference.
	Observed.	Calculated.	
12°·97	4·4240	4·4226	+0·0014
24·57	4·3042	4·3064	−0·0022
37·95	4·1769	4·1776	−0·0007
54·40	4·0278	4·0268	+0·0010
69·48	3·8973	3·8961	+0·0012
82·88	3·7864	3·7859	+0·0005
94·43	3·6942	3·6954	−0·0012

$$\lambda = 4{\cdot}5576 - 0{\cdot}010607t + 0{\cdot}00001563t^2.$$

		Reduced to 0°.
The conducting-power found in a former research was	4·35 at 20°·9	4·565

* Philosophical Transactions, 1863.

‡ Ibid. 1860, p. 161.

Table XXVII. (continued).

3.

†$Bi Pb_2$, containing 53·74 volumes per cent. bismuth.

Length 224 millims.; diameter 0·643 millim.

T.	Conducting-power.	Interval (h m)	
96°·6	1·8543		1st day.
16·5	2·0385		
12·5	2·0346		2nd day.
12·5	2·0296	> 1 10	3rd day.
93·8	1·8539	> 4 15	
97·0	1·8708	> 30	
12·8	2·0683		
10·5	2·0277	> 1 30	4th day.
97·8	1·8617	> 5 10	
93·8	1·8848	> 25	
11·7	2·0831		

The conducting-power found in a former research was 2·09 at 22°·2.

4.

†$Bi Sn_8$, containing 25·04 volumes per cent. bismuth.

Length 194 millims.; diameter 0·713 millim.

T.	Conducting-power.	Interval (h m)	
94°·8	5·3564	> 5 0	1st day.
88·4	5·4696	> 30	
11·6	6·7776		
7·5	7·6698	> 1 30	2nd day.
89·5	5·6474	> 4 45	
92·9	5·3921	> 30	
12·3	6·7511		
10·3	7·6086		3rd day.

The conducting-power found in a former research was 7·82 at 24°·9.

5.

†$Bi_4 Pb$, containing 90·28 volumes per cent. bismuth.

Length 90·5 millims.; diameter 0·689 millim.

T.	Conducting-power.	Interval (h m)	
10°·3	0·5299	> 1 50	1st day.
94·4	0·5615	> 3 0	
94·1	0·5654	> 1 0	
13·3	0·5439		
10·0	0·5402	> 2 0	2nd day.
94·6	0·5682	> 0 30	
13·6	0·5437		
6·0	0·5413	> 1 0	3rd day.
93·8	0·5686	> 4 0	
94·0	0·5682	> 0 30	
9·6	0·5430		

The conducting-power found in a former research was 0·521 at 20°·0.

These results need a little explanation; on the first two series no remarks are necessary, but on the three last we will say a few words. On experimenting with a wire of $Bi Pb_2$ we observed nothing remarkable at first, but after making a series of observations at different temperatures up to 100°, on cooling the wire the same conducting-power was not observed for the same temperature as when heating; at first we thought this was due to the wire being badly soldered, but on resoldering it the same results were obtained. In the Table the third series will read thus: at 96°·6 the conducting-power was found 1·8543; on cooling rapidly to 16°·5 it was found equal to 2·0386; on testing it the next morning at 12°·5 it was 2·0346, showing a loss in conducting-power, for it ought to have conducted better, as the temperature is lower; on the third morning we find it still lower; and on the same day, after being kept at 100° for about 4½ hours,

it, on being rapidly cooled, was 2·0683 at 12°·8, showing again an increment. On the fourth morning, at 10°·5, it was 2·0275, and after being kept for 5 hours at 100° and rapidly cooled, it was 2·0837 at 11°·7. There must be, therefore, with some of the bismuth alloys, some disturbing cause, which may act either in the one direction or the other, for on investigating the Bi Sn_8 series the opposite effect is produced. This disturbing cause may be so great that, as in the case of Bi_4 Pb, it appears as if the conducting-power increases with an increase of temperature. Other alloys of bismuth and lead, rich in bismuth, give the same results. As yet, we have not had time to investigate thoroughly this curious property of the bismuth alloys; we hope, however, to be able shortly to do so, as well as explain the reason of these remarkable exceptions to the law, that the conducting-power of alloys decreases with an increase of temperature.

3. Respecting the parts the metals take in the conducting-power of their alloys, we are at present unable to give any definite data; we did hope at one time to have deduced them with the help of the results in this memoir. It is scarcely necessary to point out that in many cases the composition of the alloy may be deduced from its conducting-power in the same manner as it may be from its specific gravity; for as

$$\mathrm{Po} : \mathrm{Pc} :: \lambda_{100^\circ} : \lambda'_{100^\circ}, \quad \ldots \ldots \ldots \quad (1)$$

then if Po and λ_{100° be determined, Pc being known (=29·307), λ'_{100° can be calculated, and from it the relative amounts of the component metals for

$$\lambda'_{100^\circ}=\frac{xc+(100-x)c'}{100},$$

where x represents the volumes per cent. of the one metal, $(100-x)$ those of the other, and c and c' their conducting-power at 100°.

Thus the observed conducting-power of the gold-silver alloy at 100° is 14·05, and its percentage decrement 6·49,

$$\lambda'_{100^\circ}=\frac{14{\cdot}05\times 29{\cdot}307}{6{\cdot}49}=63{\cdot}45,$$

therefore

$$63{\cdot}45=\frac{71{\cdot}56^{*}x+55{\cdot}90^{*}(100-x)}{100},$$

or

$$755=15{\cdot}66x,$$

$$48{\cdot}20=x.$$

The amount of silver in the alloy was 47·92 volumes per cent. Again, the platinum-silver alloy, containing 19·65 volumes per cent. platinum, conducts at 100° 6·49, and loses in conducting-power between 0° and 100° 3·10 per cent.; calculating in the same manner the percentage amount of silver, we find it equal to 82·67 instead of 80·35. The values deduced for the percentage amounts only agree in a few cases well with those found by analysis, as slight errors in the determinations materially affect them; for instance, if the conducting-power of the gold-silver alloy were equal to 14·20 at 100°

* Observed conducting-power of silver and gold at 100° (Philosophical Transactions, 1862, p. 24).

instead of 14·05, the volumes per cent. of silver deduced from that value would be 52·62 instead of 48·20, the value calculated from the latter number.

4. It may be as well to state in a few words how we determine to which class a metal belongs, whether to the lead, tin, &c., or to the gold-silver, &c. class; to do this it is only necessary to alloy the metal with traces of lead, tin, &c., and if the conducting-power be equal to that of the mean of the components, we say it belongs to the lead class; if, on the contrary, the alloy has a lower conducting-power than the mean of the components, we say it belongs to the gold-silver, &c. class. These are only some of one series of alloys which have a higher conducting-power than the mean of their components, and these are the amalgams.

Table XXVIII. shows that the new metal thallium belongs to the gold-silver, &c. class.

Table XXVIII.

1\.

Thallium, containing 5 per cent., by weight, tin.

Length 188 millims.; diameter 0·443 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	8·196 at 12°·6	8·522
Ditto, after being kept at 100° for 1 day	8·131 at 12·6	8·455
Ditto, for 2 days	8·097 at 9·8	8·347
Ditto, for 3 days	8·111 at 9·6	8·356

T.	Conducting-power.
10°·0	8·100
55·0	7·093
100·0	6·313

$$\lambda=8·355-0·026075t+0·00005654t^2.$$

Table XXVIII. (continued).

2\.

Thallium, containing 5 per cent., by weight, cadmium.

Length 163 millims.; diameter 0·431 millim.

		Reduced to 0°.
Conducting-power found before heating the wire	8·670 at 14°·4	9·141
Ditto, after being kept at 100° for 1 day	8·744 at 12·8	9·168

T.	Conducting-power.
13°·0	8·737
56·5	7·454
100·0	6·398

$$\lambda=9·165-0·033663t+0·00005998t^2.$$

These alloys were not analyzed, the 5 per cent. of foreign metal being added to the thallium fused under cyanide of potassium. From the results it will be seen that they both conduct in a lower degree than the mean of their components; for both cadmium and tin conduct better than thallium, the conducting-power at 0° of cadmium being 23·72, and that of tin being 12·36.

5. In conclusion, we would point out that the law which we have deduced from our experiments only holds good in cases where the alloy may be considered a solution of one metal in the other, the metals belonging to the same class; when the alloy is composed of metals of the two classes, then the law no longer holds good (except for a few of the alloys), even if the alloy be a solution of the one metal in the other. The results which we have obtained and described in this memoir fully bear out the views put forward in a former one regarding the chemical nature of the alloys*.

* Philosophical Transactions, 1860, p. 161.